St. Petersburg University
Graduate School of Management

Master in Management Program

COST ALLOCATION METHODS IN COLLABORATIVE LOGISTICS

Master's Thesis by the 2nd year student
Concentration — International Logistics
and Supply Chain Management
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ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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АННОТАЦИЯ

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Описание цели, задач и основных результатов	Целью данной магистерской диссертации является заполнение существующего пробела в теме партнерской логистики путем предложения нового метода объединения розничных компаний на уровне хранения запасов и нахождения устойчивого механизма распределения затрат в смысле отклонения произвольной коалиции. Партнерская логистика подразумевает объединение двух и более компаний для оптимизации операций. В результате исследования основных тенденций в существующих научных статьях по теме партнерской логистики и выявления пробелов и ограничений, был разработан новый метод для совместного управления запасами. Для такого метода был предложен механизм распределения затрат, устойчивый в смысле отклонения произвольной коалиции. Также метод реализован на примере розничных компаний. Результаты работы показали, что сотрудничество в области управления запасами оказывает положительное влияние на уменьшение затрат и тем самым стимулирует партнерство. Кроме того, найден механизм распределения затрат. Для построения такого механизма использовался теоретико-игровой подход. Было доказано, что в исследуемой задаче С-ядро непусто, вектор Шепли находится

	внутри С-ядра, а значит, существует такой способ распределения затрат, при котором отклонение любой коалиции розничных компаний от кооперативного поведения экономически невыгодно.
Ключевые слова	Управление запасами, экономический размер запаса, кооперативная игра, С-ядро

ABSTRACT

Master Student's Name	Kupetskaia Alina
Master Thesis Title	«Cost allocation methods in Collaborative logistics»
Faculty	Graduate School of Management
Main field of study	International logistics and supply chain management
Year	2017
Academic Advisor's Name	Andrey V. Zyatchin
Description of the goal, tasks and main results	This master thesis aims to fill the existing gap of collaborative logistics by proposing retail companies a new method of collaboration on inventory level and finding sustainable cost allocation mechanism in a sense of deviation of arbitrary coalition. Collaborative logistics assumes a partnership between two or more companies for operations optimization. Resulting from examining trends in existing scientific articles on collaborative logistics and finding limitations and gaps, a new method for collaborative inventory management was developed. For such a method, a cost allocation mechanism that is sustainable in a sense of deviation of arbitrary coalition was proposed. Moreover, the method was implemented on retail companies. The results of the work showed that cooperation in the field of inventory management has a positive impact on cost reduction and thus stimulates collaboration. In addition, a cost allocation mechanism was found. To construct such a mechanism, a game-theoretic approach was used. It was proved that in the problem investigated the core is not empty, the Shapley value is located inside the Core, which means that there is such a method of cost allocation that deviation of any coalition of retail companies from cooperative behaviour is economically unprofitable.
Keywords	Inventory management, Economic Order Quantity, cooperative game, Core

Introduction

Background

Logistics and supply chain management gained a lot of attention in last 45 years from the time it appeared. Previously, the company perceived the transportation as a separate type of operations, but now the concept shifted towards the better firm performance to the higher customer satisfaction rate. This can be reached through different ways: better service quality, closer relationship with customers or collaboration on different levels.

Nowadays, scientific articles on Logistics and Supply Chain Management topics are very popular. However, the collaboration process on supply chain level is not the mostly developed one; it still has some gaps. Some existing articles on the topic of supply chain collaboration are devoted to the transportation problem; others are limited in terms of applicability of the method developed. The last may refer to the type and level of supply chain type collaboration practice is suitable for, the number of players or stability of the cost allocation decision.

Moreover, many authors prove that inventory takes the biggest part of the cost structure in the whole supply chain, while efficient inventory management is key for better performance of companies. That is why this master thesis is devoted to the stable cost allocation mechanism for collaborative inventory management.

Purpose of the study

The research subject is collaborative logistics in the scope of inventory management. Retail companies of Saint Petersburg and Leningrad region are objects of the study. This paper aims to propose a new method of collaborative inventory management for retail companies and find sustainable cost allocation mechanism for this method.

To achieve the goal several objectives are set:

1. Examine trends in existing scientific articles on collaborative logistics to find limitations and gaps
2. Develop a new model for collaborative inventory management
3. Propose cost allocation mechanism suitable for the new method and stable against deviation of any coalition
4. Implement this method on real cases of retail companies

Research questions

In order to complete the tasks, the next research question is formulated:

How can competing companies allocate costs from collaborative decision making in inventory management?

The research question can be answered through applying quantitate and qualitative research methods. For the qualitative research, case-study investigation, secondary sources analysis and benchmarking on contemporary analytical studies are conducted. Observation, analysis of reports and individual interview are provided for qualitative analysis. Economic Order Quantity Model as well as game-theoretical approach are streams for running quantitative analysis. The Core of the game and Shapley Value are two main mechanisms used as quantitative methods for answering the research question.

Structure of the study

This paper consists of 4 chapters. The first chapter is devoted to the stability problem of cooperative decisions in supply chain. As companies tend to change in order to increase the service level and to be more flexible and agile, collaborative initiatives take place. This require stable cost allocation agreements before the implementation of collaborative practices. Chapter 2 describes the methodology needed to fill in the gap and develop new method. It also includes the extended framework that has resulted from the implementation of initial method on real cases. The main difference is the variance in demand of players in a coalition. The third chapter includes explanation of case selectin procedure and represents results and outcomes. The forth chapter formulates the main theoretical and managerial contributions. Moreover, limitations of the research as well as further directions are included in the final chapter. This paper is useful for the companies willing to decrease logistics costs by collaboration in inventory management.

Chapter 1. Stability problem of cooperative decisions in logistics and supply chain management

1.1 Inventory management in logistics and supply chain management

The term of supply chain management (SCM) is a combination of different disciplines. Nowadays, there are a strong misunderstanding of the concept. SCM has attained growing attention from practical and academic societies as a crucial discipline (Shafieezadeh et al., 2015). A wide range of contrasting definitions can be found in different sources. The most popular and widely-used interpretation of SCM is “the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities” (CSCMP 2007).

Several reasons explaining the challenges connected to the misunderstanding of the concept of supply chain management may be found in the literature. Recent article by by Fedotov and Krotov (2011) is not an exception. In a paper “SCM: In search for definition” authors point out several ideas and explain the gradual historical changes of the definition. According to the writers, the first reason for the misinterpreting of the concept is the differences in perception of the term. Discussions of the definition is described by them in the first part of the article.

Supply Chain Management includes the tasks of 3 different disciplines: logistics – minimizing the transportation costs, operations management – inventory and production control and client orientation from marketing (Fedotov and Krotov 2011). According to the authors, the SCM approach erased in late 1970s – the beginning of 1980s when economics and enterprises were straggling from the crisis and the only way to survive was minimizing the logistics expenditures. However, the reason for the high price of cargo process is one resulting from bullwhip effect. This bullwhip effect arises when business partners do not realize the real demand on different stages of logistics process and thus have to deal with enormous safety stock, that is extremely costly.

The next problem discussed by Fedotov and Krotov is the limitation of the empirical approach. The main constrains are single-level nature of the research, small sample size and limited methodological analysis. Moreover, the scientists today ignore some practical decisions implemented by business; on the other hand, some research concepts are too theoretical for the real life.

The last but not the least issue depicted in the article (Fedotov and Krotov 2011) is one linked to the problems of the limited number of studies in Russia. The reason for this is lack of scientific magazines and low quality of the published studies. Some editions have a tiny interest in this sphere – logistics and SCM, and prefer other topics, for example marketing, mathematics and chemistry.

Another article about the problem of interpreting the definition of supply chain management is published in the Journal of business Logistics (Mentzer et al. 2001). The main idea of the paper is that yet there is a strong interest towards the supply chain management resulted from the changed preferences in recent years, there is still a reasonable flap about its essence. Thus, the authors refer to the existing definitions of the concept and explain the possible reasons for this variety.

The development of the concept of logistics is also presented in the paper by Tseng (Tseng, Yue and Taylor 2005). The authors state that the logistic process was in recent years one of the useless steps in a production and sales process. For many years managers were strongly concerned with production lines capabilities and revenue from sales excluding the importance of the transportation. For the timeline of the logistics process described in a paper, see Figure 1.1.1 (Tseng, Yue and Taylor 2005).

1950s		**1970s**		**1990s**		**21st century**
Dormant Years	→	Development years	→	Take-Off Years	→	Globalization Logistics

Figure 1.1.1 Timeline of the logistics development

Concluding from the outline, before the 1950s logistics was very passive and a society did not pay enough attention to it. All the people were concerned with the sales and left the transportation without the attention needed. They deal with it only because they have to, but did not accept it as a source of optimization or making the company more efficient. In the period of 1960s - 1970s, some researches like P. Drucker began to think about the logistics in another way and started the development of very new approaches. In the 1080s - 1990s more and more investigations appeared and the logistics become a necessary part of the entire process of the production. In the beginning of the 21st century 3PL providers and global logistics became main features of the concept.

Due to the lack of common definition of the supply chain, the authors (Mentzer et al. 2001) propose a comparative table of different approaches to the term. A huge part of the research is devoted to the scope and consequences of the supply chain management implementation. Menzter created a framework that aimed to help the companies to include and use all the levels of supply chain in management system. In order to satisfy them all, managers should operate with all these functions of supply chain. A tool for the precise and deep analyse of SC is shown on the Figure 1.1.2 (Mentzer et al. 2001).

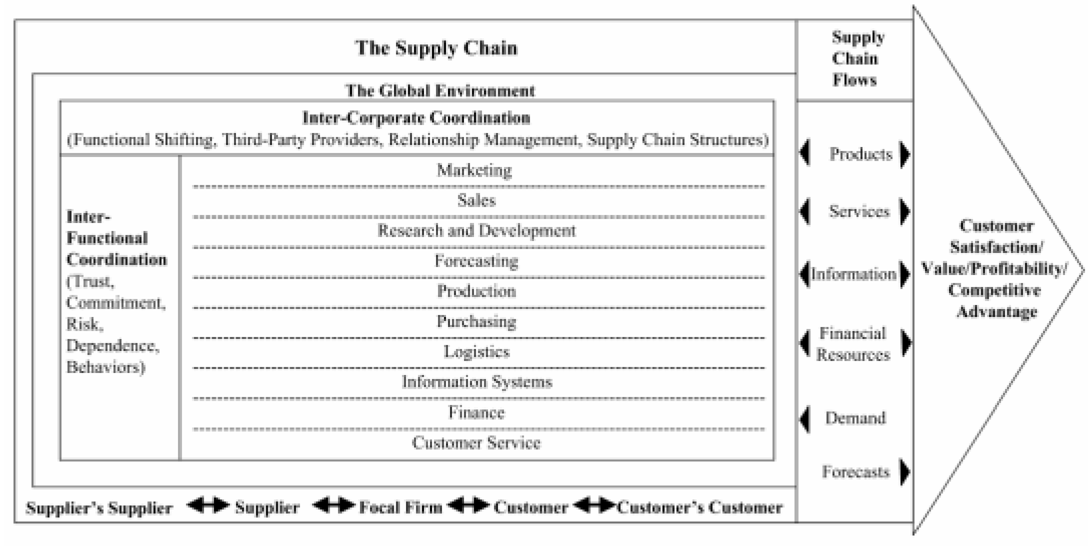


Figure 1.1.2 The supply chain framework

This figure explains that without a deep understanding of this interrelations a supply chain of the organization could not operate efficiently. It also crucial to know that the vast majority of operations in the supply chain are global and require comprehensive analytics from managers including all the flows of operations.

The interrelationships between logistics and transportation took an attention of researches Tseng, Yue and Taylor (2005). The core message is that without appropriate transportation, logistics and especially supply chain could not operate correctly and into a full scope. The right chosen transportation process has to influence the firms' performance as it has to cut costs, reduce inventory level and as a result increase the effectiveness and profitability of the company.

Moreover, the authors distinguished different forms of logistics operations: supply chain management, reverse logistics, maritime logistics, air freight logistics, land logistics, express delivery, and e-commerce (Tseng, Yue and Taylor 2005).

Three main parts of supply chain management are manufacture, transport and purchase. These three elements are essential for the operations of the company. It also includes the information flow that intersects all the timeline parts from the manufacturing until the final step - reaching the customers. Reverse logistics is extremely important nowadays due to the higher customer service level, usage of renewable resources and extremely high value of the time. It is a process of returning the packages, pallets to the supplier in order to reuse it in the future. This process helps to reduce costs, make a lot of durable products for the transportation and influence the environment. Nowadays, creating reverse logistics routes takes at least the same passion as creating a normal logistics routes.

Another part described in the article (Tseng, Yue and Taylor 2005) is a maritime logistics. It has a huge impact on overall good transportation because it is a cheap and convenience way of products freight. Many companies prefer this kind of cargo services as they are not expensive and ships may be filled with a huge number of different items. Air cargo is necessary for some industry. The transportation by air is secure, fast and flexible. That is why for some products like medicals, valuable goods and post items, suppliers choose only air cargo. This helps to operate in efficient manner and reduce the risks connected to the safety, speed and some customs problem. The land logistics is the most popular one when companies need to transport huge number of packages that are in different countries that are not separated by sea. This type of cargo connects a lot of locations and the price for the shipment is low.

In today's world, the speed of delivery plays a crucial role in a service level. Many companies are trying to implement the just-in-time delivery model, that requires delivery that is frequent but small in volume. Express delivery can be characterised by the next features: door-to-door service; efficiency; traceability; Just-In-Time; growing various delivery demands (Tseng, Yue and Taylor 2005). Today, when the demand is growing, maritime logistics is connected with air cargo in order to obtain those features and create competitive advantage and reach the highest level of customers' satisfaction.

E-commerce may be seen as another type of modern logistics services. It reduces the number of connections in a supply chain and thus save time, lowers costs and creates a higher level of customer satisfaction. The process of e-commerce in logistics comparing to the standard supply chain can be seen on Figure 1.1.3 (Tseng, Yue and Taylor 2005).

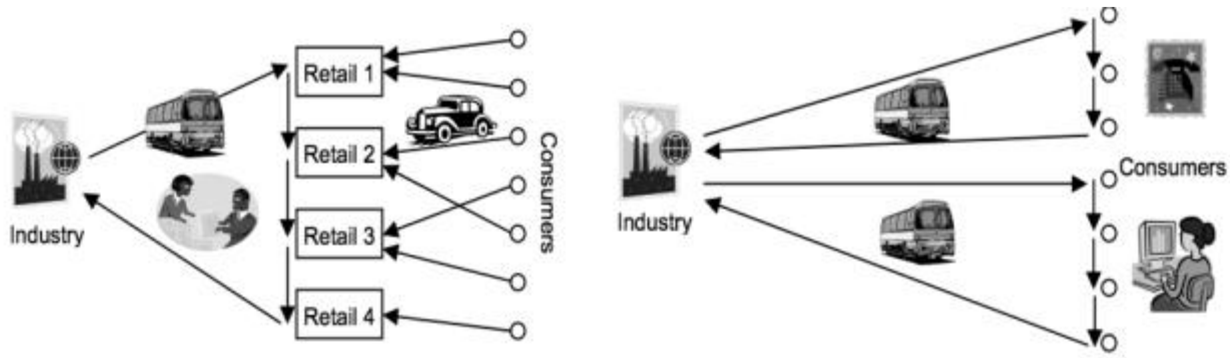


Figure 1.1.3 Comparison of e-commerce in logistics and standard supply chain

Moreover, the e-commerce has a huge impact on customer and suppliers' relationships. It transferred from the local into the global perspective, decreased the number of warehouses and limited the stocks level. In addition, it uses the IT and software solutions instead of so widely-acceptable paper blankets that slower the speed of operations and decrease the efficiency as well as profitability of the company. On the other hand, e-commerce has a great pressure on the standard companies that has to enlarge their inventory level in order to stay in a game, to beat competitors and be able to satisfy all the demand of customers on different channels.

One of the vital dimension companies compete on, is inventory management. In order to understand deeply what terms are used in this master thesis, a set of definitions (adopted from Phull, Lawton and Montague 2017) is formulated (Table 1.1).

Table 1.1 Definitions of inventory terms

Terminology	Definition
Inventory	Products in our stock that are kept in order to meet the demand when needed
Inventory balance/ current inventory on hand	Inventory measured in currency, units and other feasible form
Days of supply	Time needed to sell all the inventory
On-time delivery	Ratio of orders delivered in time to late deliveries
Inventory accuracy	The difference in available inventory and reordered level
Inventory stock-outs	Amount of orders that were not satisfied due to the lack of inventory

According to (Kanda and Deshmukh 2008), inventory management is not a combination of technics helping to manage inventory, but a holistic approach that gather all aspects of supply chain. Effective and efficient inventory policy are core competences of successful businesses (Coelho, Cordeau and Laporte 2013). The key to be competitive is to find a balance between inventory investments and customer satisfaction. Very often companies tend to spend too much on inventory willing to be able to deliver goods as fast as they can, but poor inventory management results in a long delivery time (Toth and Vigo 2014). The task of inventory management is to find the quantity of inventories that will fulfil the demand, avoiding overstocks (Plinere et al., 2015). Inventory costs of materials and finished inventories make nearly 20 to 60% of total asset costs (Gumus and Guneri 2007). While companies are aiming to keep inventory at warehouses at the level that can satisfy the demand, the holding costs for it are frozen and can be seen as losses. The main goal of inventory management is to find the right amount of order, understand when to place the order and realize how much to keep in inventory. That is why, different forms of better examination of inventories are applied today on practice in order to decrease costs and result in a firm better performance.

Yet there is enormous amount of inventory management systems, in this paper only few are going to be discussed. The most famous strategies are: conventional manufacturing strategy, just–in–time delivery (JTD), materials required planning (MRP) and economic order quantity

(EOQ) system. The traditional system assumes the constant process of ordering products. JTD bases on the placing orders for products exactly when company needs them. MRP includes planning based on the sales forecasts. EOQ model assumes that the demand is constant and inventory decreases over time. Companies implementing EOQ system, continuously monitor the stock level and decide when to place the order. In practice, company might use several other strategies. Some of them are p- and q-systems, assuming periodic review strategy and ABC-XYZ matrix, helping to assess the inventory categories in revenue structure and manage different groups variously. Another example is vendor managed inventory (VMI), that assumes the management of the stocks by supplier. A lot of articles are devoted to the analysis of relationship of VMI or other collaborative practices and firm performance (Wadhwa et al. 2010).

Contemporary analytics as well as researches argue that yet there are benefits resulting in better firm performance from integrated practices (Lyu, Ding and Chen 2010), a lot of difficulties occur when collaborative inventory management takes place (Archetti and Speranza 2016). Some of them are more difficult management system, complexity connected to the conducting of the integration.

The models applying today on a practice is not obsolete. There is a need to work over existing models in certain directions, enrich it, open new horizons, improve it and develop. Additionally, in a current global scope, managing efficient supply chain within one organization is almost impossible. Many companies realize that playing, operating jointly creates an opportunity to get a lot of advantages (Marquès et al. 2010). If a company cooperates with other companies in order to obtain benefits, the scenario of the game changes. The process of this in a literature named as a collaborative logistics. Because supply chain collaboration is poorly determined term (Naslund and Williamson 2011), it can include everything from information exchange to the mutual decision making (Ajmera and Cook 2009). In order to implement the collaborative strategy, the process of aggregation occurs.

1.2 Aggregation and planning in logistics

To reach higher level of supply chain management, companies tend to combine facilities to better predict the demand and improve the customer satisfaction. When companies forecast, plan and replenish the goods together, the process is called collaborative planning, forecasting and replenishment (CPFR) practice. In such a model, combining many variables make them aggregated. This eliminates the stockouts, surpluses and affect the efficiency of companies. Altogether, companies tend to cooperate in order to gain benefits and increase the profitability. CPFR creates value to end customers and improves overall SC performance by providing standardized information and establishing objective plans that allow for an efficient flow of goods based on demand (Shu et al. 2010).

Depending on the number of horizontal supply chain partners involved in CPFR, the structure can differ; see Figure 1.2 (Min and Wenbin 2008).

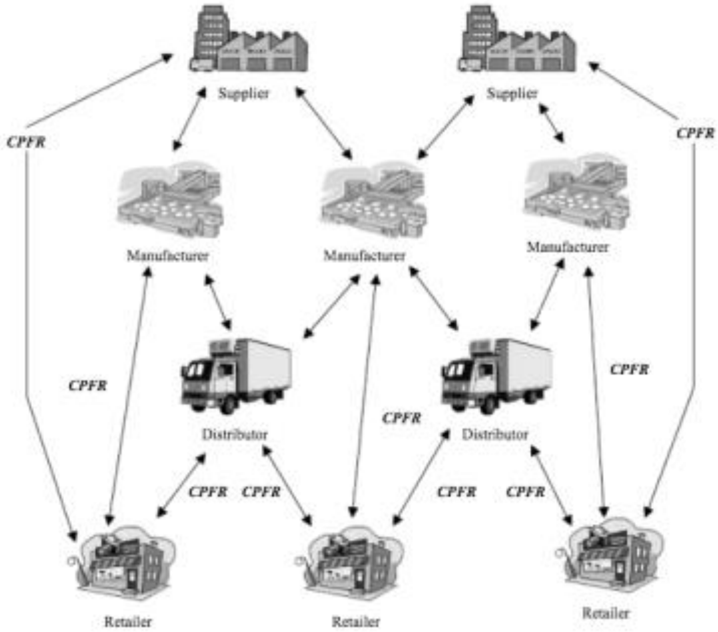


Figure 1.2 SC structure aligned with the number of partners involved in CPFR

In a paper by Kim and Mahoney 2009, the process of CPFR is described as a relational contract with its incomplete perspective. Despite the fact that all the benefits of correctly implemented CPRF practices are obvious, not all the companies can achieve it.

The precondition of the paper was a case of Wal-Mart, which is the most known retail chain, which is efficient in terms of logistics operations. To refer to the history, the main features of the Wal-Mart's strategy are keeping less inventory and decreasing safety stock, ordering constantly in the same amounts from the suppliers and selling without discounts. All these practices contribute to the saving costs, predicting and stable demand for all the participants in a logistics chain and lower prices for the customers. That is also an example of how to overcome the bullwhip effect and be successful.

One of the major concepts of the article (Kim and Mahoney 2009) is a process of creating a competitive advantage with CPFR solution. The authors state that to gain economic value companies in a coalition should understand and investigate on the structure of vertical relationship, find out the impact of experience and information sharing.

In the article by Kim and Mahoney, CPRF is characterized as a "relational contract in which electronic information sharing and common organizational procedures for joint activities play a critical role in coordinating interdependent tasks between trading partners in the vertical chain" (Kim and Mahoney 2009). Moreover, in a research the writer implements the ideas for future investigations of the problems related to the information sharing. Another challenge that may occur when changing the policy of CPRF, is a managerial issue. By this author suggests the human problem of changing the players in the contract and thinks about the credibility of it at the same time.

One of the practical implications in a paper is a comparative matrix of CPRF practice with the standard vertical relationships. The authors provided a case-analysis of Wal-Mart and its relationship with P&G. As a result of the research, the application of a choice of relationship can be pointed out. In order to generate the maximum profit and choose the most prominent variation of the relationship, the analysis of the partners in terms of transaction and agency costs should be made. The framework is represented in a Table 1.2 (Kim and Mahoney 2009).

Table 1.2 Impacts of CPFR on organizational economics and inter-firm governance

		Transaction costs due to demand uncertainty and asset specificity	
		High	Low
			Relational contracting
Agency costs due to information asymmetry and task complexity	High	Vertical integration	CPFR
	Low	Long-term contracting	Standard contracting

The most vital insights of this implication: without deep understanding of the strategies and economic incentives of the partner, it is too unpredictable to cooperate. What is hidden behind this is that partners may be afraid that another partner will use the advantage because of the knowledge sharing. The reason for this is that knowledge sharing is deeper and more open comparing to the standard vertical relationships. That is why partners need to be sure in each other behavior, in a common goal and trust each other.

In a real world, the difference of benefits possible between vertical integration and collaboration is not obvious. That is why authors also bullied six suggestions when certain conditions presuppose implementation of CPFR practices instead of vertical integration contracts.

1. When there is a strong information asymmetry and the goal of the project is too complex to maintain it without knowledge sharing;
2. When the bargaining power of the partners is controlled by independent agreement and contracts;
3. When all the parties are interested in in the constant development and improvement of the collaboration;
4. When the fluctuation of demand is huge and all the partners control this by agreement and IT systems;
5. When the compulsory assets divided equally between parties and all they have the same access to them;

6. When partners work together over the intellectual capital improvements by collective agreements.

Only with the compliance of these suggestions, the relationship of the partners will lead to better results of a coalition. Of course, those proposed by the authors contain some limitations, but for companies with little experience, this can be helpful.

The process of CPFR may be described (VanDeursen 2010) as a roadmap, which is described further.

The first step of the process of making the CPFR process dynamic is defining partner opportunities. In this period, a company should list all the possible partners and count the benefits from creating a coalition with them. Next, the understanding of business drivers should be achieved. If the core activities differ very much in different companies, the benefits may not be gained. Alignment of supply basics is the next crucial point a company should pay attention to. When the collaboration is created, the integration with additional business processes have to be done. The process of combining all the supply chains, marketing and sales activities have to be accomplished before starting the next step. Joint definition of success metrics if another critical step in a process. Each party should reconcile benefits in order to find out the results of cooperation. Next, the company should move from their company forecasting to the wide supply chain predictive modelling. In order to create a valuable collaboration, company should negotiate and work on the same problems with the same data sets. In most cases collaboration might reduce the stock or inventory level by 40% in one year (VanDeursen 2010). But, this changes in a public company may be seen in a market as a bad sign. There is a task to keep the image of the company positive. The tool companies use (IT systems) should be easy to use as well as secure to be sure that due to the information sharing no one of the partners will get a competitive advantage. All these steps lead to a dynamic collaboration and should be followed by partners. The final and closing point is to leave room for expansion. There is always a way to improve partnership and everyone should work on the task.

The above-mentioned approach was created in order to help companies to generate the competitive advantage and make CPFR strategy dynamic. Nowadays, companies are trying to collaborate, but the effort is not maximum. If the CPFR practices implemented correctly and companies are energetic, the strategy itself will cut costs, decrease the inventory level, make the cooperation within the coalition beneficial, and reduce the bullwhip effect.

1.3 Collaborative logistics and cooperative decisions

When there is a need to improve current performance, shake the company's stability, managers tend to implement the strategy of sharing mutual ideas and collaborating with different companies. The partnership may be investigated on different levels. It can be a process of collaboration on different stages of one supply chain, a collaboration between different companies or a collaboration on different levels of supply chain – vertical relationship. In this master thesis, the horizontal collaboration on inventory management level both within different companies and within one company is examined.

Collaborative logistics is a process of creating a partnership between two or more companies by sharing, subleasing and using vehicles, assets, and processes for achieving certain results. As it is explained in a paper (Min and Wenbin 2008) collaboration in logistics is a way to make operations smoother and increase the company's performance. Supply chain collaboration as any process that spans across corporations, provides an opportunity to work collaboratively with the intention of providing better planning, execution, or information sharing.

In a collaboration, there could be a lot of participants. In a very simple model there could be only two sides: inflow, that represents the supplier and outflow, that represents the customer. However, in each side there is a lot of suppliers as well as customers.

A lot of benefits from participating in a collaborative logistics could be pointed out. The main of them, according to Hockey Min, are less inventory and a cost reduction as a result, faster communication with customers and better firm appearance, larger market share and faster production flow.

The article by Pamela Danese (Danese 2011) is focused on the strategy of different forms of collaborative activities choice. According to the paper, the main collaborative planning initiatives are vendor-managed inventory (VMI), continuous replenishment (CR) and collaborative planning, forecasting and replenishment (CPFR). In the literature, the process of implementing collaboration between companies is seen as an evolutionary process from very simple activities to the most complex ones. However, in this case, it is assumed that the collaboration is a context-free and depends only on the recourses of companies. That is why author suggests a solution for two research questions (Danese 2011):

1. How do contextual factors affect collaborative planning initiatives in supply networks?
2. Why companies choose different types of collaboration practices?

The article describes 10 real cases, analyzes it and propose a model that aims to help to choose appropriate form of collaborative initiatives. Depending on level of integration and multiplexity, different forms of collaboration are proposed – "communication, limited collaboration and full collaboration" (Danese 2011). Moreover, the main conclusion of the article is that it is not obligatory for companies to strive to achieve the highest level of collaboration and implement the CPFR practices. Even it might be seen as the most attractive initiatives, the precise and detailed examination of what is needed for this exact company should be provided. Sometimes it is worth to limit the collaboration and focus on the internal business. Yao, Evers and Dresner (2007) state that VMI helps companies to keep less inventories and stimulate smaller order size.

However, sometimes the participation in a collaboration is not a voluntary. There is a question of an effort and the utility one particular business bring to a collaboration. Sometimes, huge corporations are in a coalition with smaller businesses and in this situation, the impact of each particular company is not equal. That is why a question of staying in a coalition is vital. Moreover, the question of how to share the payoff of benefits or how to split cost are also arises.

R.P. Kampstra and J. Ashayeri discuss the reality of collaboration issues in their paper (Kampstra, Ashayeri and Gattorna 2006). They cover four main problems of the collaboration:

1. Equality between partners

The question refers to the problem of the impact of different players within the collaboration. In addition, some players may be forced to play and face contradictions. Sometimes conflicts may arise. In order to avoid these problems, authors (Kampstra, Ashayeri and Gattorna 2006) suggest “three main roles: collaboration leader, collaboration coordinator, and remaining collaboration members”. The task of a leader is to create the coalition, count the outcomes, manage the team and make a decision. Without an approval of the leader, any decisions or changes could be implemented. Coordinator’s duties are to manage the collaboration process. The main goal is to transform the supply chain process. This member should make sure that all the changes are implemented, the chain operates efficient and all members agree. All the other representatives should have an option: whether to stay in a collaboration or to leave.

2. Consequences of collaboration. Are they ongoing or limited?

In terms of the outcomes from the collaboration, two possible variants can appear. The first is the ongoing collaboration and the second is limited. The results depend on the process itself, however some core reasons for each specific fallout pointed out (Kampstra, Ashayeri and Gattorna 2006). The main reasons for blocking collaboration are: shortages of raw materials, market and policy constraints. The moderations for the ongoing process: creative and innovative chain, communication among the members of collaboration and equal priorities.

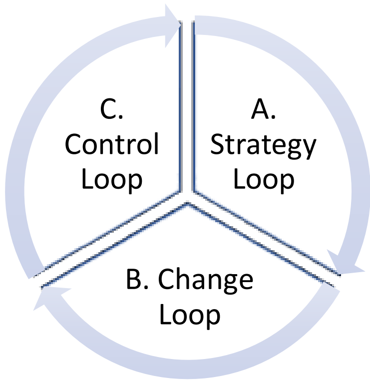
3. Potential of players to collaborate

In addition, authors (Kampstra, Ashayeri and Gattorna 2006) state that different collaborative models have different constraints and thus effects. Four main types of collaboration practices are characterized in a paper. As a result, the major recommendation for the collaboration from Kampstra is not to treat evenly the partners in collaboration. The reason is that some suppliers are more powerful and thus have stronger value and vice versa.

4. Balancing priorities

Regarding the priority balance (Kampstra, Ashayeri and Gattorna 2006), researches assume two main difficulties: the first is tied up with understanding the vices of existing collaborations, the second one is about distinguishing internal and global benefits from the collaboration.

Furthermore, as collaboration build on constant decision-making, a lot of loops may occur. Authors (Kampstra, Ashayeri and Gattorna 2006), propose three main categories of the loops. The categories and a suggestion of how to deal with them is represented, see Figure 1.3.1



A1 Choose strategic partners
A2 Identify Supply Chain strategy
A3Align with corporate strategy

B1 Which entities should change?
B2 What should change?

C1 Govern transformational changes
C2 Govern strategic objectives
C3 Allocate benefits and burdens

Figure 1.3.1 Categories of different loops possible in a collaboration

It is easy to notice, that the effort of different participants is not equal. Thus, the analysis of different variations of collaboration game should be done before the collaboration starts.

Before sharing the profit, a company has to determine which partnership is more profitable and interesting for it. As coalition tends to cut the expeditors costs of the partners, organizations can achieve better financial results. But, even it is possible, the performance varies significantly depending on the parties that are in a coalition. In a paper "Determining collaborative profits." (Cuervo, Vanovermeire and Sörensen 2016), authors investigate on the different coalitions outcomes and determine the most profitable variations in example of several firms. They compare the results by looking on different characteristics of the partners and thus the coalition characteristics.

There are several motives for the company to cooperate together and build horizontal coalitions. Some of them are lowering operational costs, higher efficiency level and creating a connected operational plan. The costs that company inquire are lower than the sum of the separate costs a company may have working alone. If we subtract the one sum from another, we will get coalition gain (profit). The problem of sharing costs is vital, but in this paper the investigation on different gains depending on the different partners is described.

In the contemporary literature, the most publications are about the benefits that a coalition create. Despite the main advantages like increased efficiency and cutting the costs, coalition also contributes to the more environmentally-friendly logistics and improving the service and thus a customers' satisfaction. However, the newest articles are devoted to the specific features that make a collaboration successful.

Key findings regarding the value of coalitions (Cuervo, Vanovermeire and Sörensen 2016) are represented on the Figure 1.3.2 and Figure 1.3.3 below.

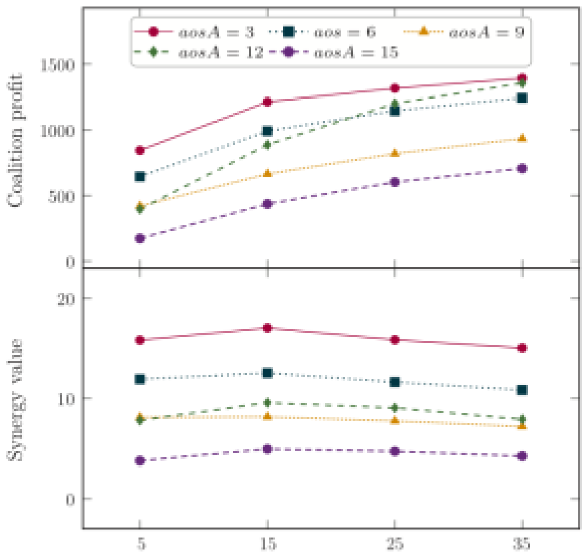


Figure 1.3.2 Average profit and average synergy value of coalitions formed when one of the partners has different numbers of orders and these orders have different sizes.

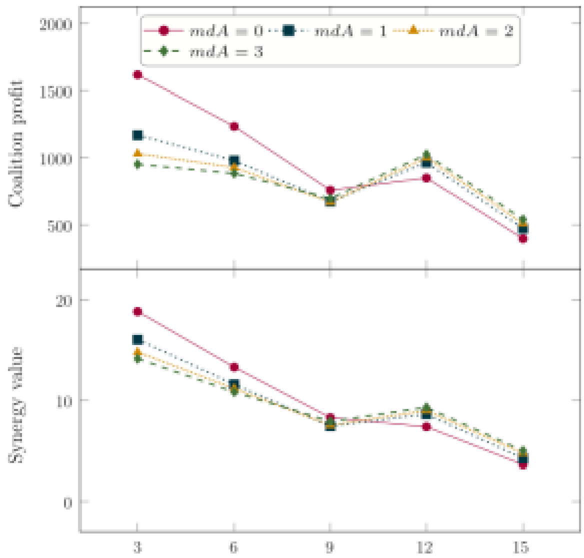


Figure 1.3.3 Average profit and synergy value of coalitions formed when one of the partners has orders of different sizes and allows its orders to be delayed.

In the article the authors conclude, that a synergy is not the most representative variable, that is why they suggest three advises for the companies that are looking for some tips of how to generate the most efficient collaboration. They are based on the findings from a paper (Cuervo, Vanovermeire and Sörensen 2016).

1. The size of the order is the most crucial indicator for the performance in a coalition. The most profitable partnerships are formed with the companies that have complementary order size.
2. Paying attention to the amount of orders a company has is also important. The higher the number, the higher its chances for the creation of the most efficient operational plan and thus coalition.
3. The possibility of the organization to postpone the orders may be helpful for some companies. If a partner in stand-alone operational plan has a lot of trucks with unused capacity, the flexibility of the orders time may increase the efficiency of the coalition with other partners.

Beside this, in a real-world perspective companies do not cooperate in a coalition with the higher gains, but cooperate with partners where their own profit is maximum. Thus, a cost allocation method may be proposed.

"Operations research models for coalition structure in collaborative logistics" (Guajardo and Rönnqvist 2015) is another valuable article for the topic. Authors created a tool for the answer of what kind of partnership should be created. The main problems covered in a paper are core stability and strong stability problems. It is a condition when all the participants want to stay in a coalition and agree to share the gain in a prescribed way. Researches used a linear programming model to achieve the result. It is a mathematic approach of finding the optimum value of certain criteria with a linear equation. They tried to find the strong equilibrium that satisfies all the companies that are in the coalition.

The paper (Guajardo and Rönnqvist 2015) is based on the calculating the outcomes in two applications – "collaborative forest transportation and inventory of spare parts for oil operations."

The authors also investigated on the cost savings that could be reached in a coalition. However, now in a scientific literature there are some core analysis of a combination of only 8 or less companies. There is still a room for the research. For the results of the cooperation between 8 companies found by the authors (Guajardo and Rönnqvist 2015), see Figure 1.3.4

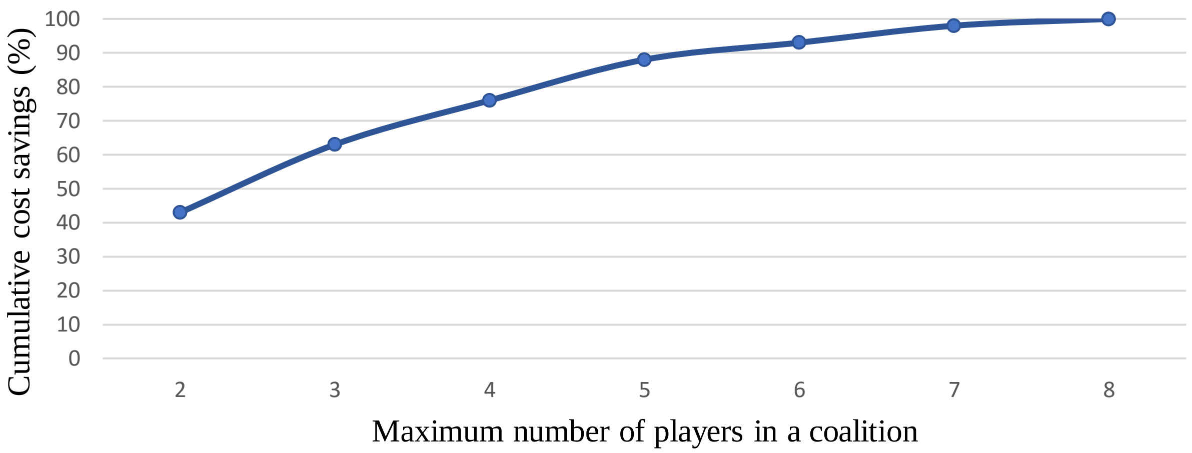


Figure 1.3.4 Cumulative cost savings from allowing one more player in the maximum allowed cardinality of a coalition

It can be seen that the cost reduction increase while the number of players increases as well. However, the maximum is reached in the coalition with 8 players. That raises a question of necessity of formation a coalition by more than 8 companies. Moreover, the proposed linear solution is held in Excel, which has a limited capacity and cannot count the outcome for higher number of companies as the variations of the combination is too huge.

According to the authors (Guajardo and Rönnqvist 2015), there is still a room for further investigations - adding additional constraints to the formula, “formulating solution methods that could efficiently find the optimal structures and cost allocation vectors”, “considering the case where they (players) can adopt non-cooperative or partly cooperative strategies”. However, the question of how to share the payoff in a game is still one that creates the hardest challenges and limitations in a collaborative logistics.

A large number of contemporary research regarding this topic is solving the problem of sharing a cost of grand coalition using “the cooperative game theory concepts” (Flisberg et al. 2015). The Core of the game is a combination of all the possible solutions that satisfy all the partners in a coalition. The authors suggest two types of cost allocation models: “proportional allocation and allocation based on separable and non-separable costs”.

The first method – proportional allocation – is a simplest one that assumes the proportional dividing costs formed by the coalition. The costs are splitting according to the value a company brings to the collaboration (saving costs). The separable allocation model assumes that a cost inquired by a company is subtracted from the total costs of the coalition. It is a marginal cost of a company that creates a coalition. The non-separable approach can be applied as a difference between all the costs in a grand coalition and all the separable costs. In addition to these models, authors implied equal profit method. This model can be described as a linear programming model that looks for the Core of the game minimizing the difference in any pair.

In the article the authors (Flisberg et al. 2015) use case-study in appliance of fossil fuels in Sweden. They suggest, that a huge potential for the cost saving comes from the collaboration. Yet they applied several models of cost allocation, the questions of coalitions formation and sharing a payoff are still open. That provide a huge potential for future investigation.

Guajardoa et al. 2016 is another paper that is devoted to the collaborative logistics. The authors concluded that a collaboration is one of the core reasons for the cost saving and increased efficiency of the company. Krajewska et al. (2008) argue that collaboration is one of the possibility nowadays for companies to compete on the market. Today, the main result of a successful coalition is not the cost savings, but the increased efficiency and better performance of the organization. Still, the main question of the collaboration is how to divide the gained benefits and who to create a coalition with.

Some suggestions of how to improve the logistics procedure in a collaboration is proposed (Guajardoa et al., 2016). The first option is to create a coalition and use shared inventory, splitting and decreasing the fixed costs. Another option is to hire the third-party logistics provider so that a company deliver the products for all the companies within the coalition. The last-mentioned approach is to share the information inside the coalition in order to obtain benefits. All these ways lead to same questions: how to share obtained benefits, how to split the costs and how to manage the coalition. The paper is concentrated on the 1st one: how to share the benefits.

Authors (Guajardoa et al., 2016) discuss two main cost allocation models: proportional allocation and one that is based on the principles of the game theory. Both methods have its advantaged and disadvantages. Guajardoa also investigated the transportation problem that seeks to the profit maximization instead of costs minimization and worked on the problem of sharing the gains from the coalition.

However, the major discussion is dedicated to the five classes of problems that arise during the collaboration. This includes:

- planning and forecasting problem (satisfying all the customers by the minimum costs and corresponding to the supply and demand flows),
- travelling problem (starting at one point, attending all the others just once and returning to the original location),
- transport choice optimization (each route starts and ends at the same point),
- distribution and delivery related problems,
- merged inventory.

Fang and Cho (2014) looked at the inventory transshipment among several companies and found that the networks are stable only under several conditions. They studied decentralized system inventory combinations. Furthermore, the cost allocation methods minding each of the problems is proposed. This paper adds a huge value to the topic investigation.

1.4 Research Gap

Recent researches have shown the importance of improving the supply chain competitiveness by means of partnerships (Pasandideh, Niaki and Nia 2010). Other studies reviewed show that a concept of a coalition formation in collaborative logistics, inquiring costs and sharing a payoff are crucial and still not fully examined. Moreover, the coalition between competitors on different stages of supply chain is still not investigated. Inventory management plays a significant role of the managing and improving SC operations. Thus, the model for competitive collaboration and inventory management has all the chances to be practical and useful. Yang et al. (2015) states that warehouse collaboration implementation is beneficial.

Flisberg et al. 2015 note: “The results clearly show a great potential and any such sub coalition has a basis for further studies but for smaller sized coalitions… it is possible to form coalitions containing not only full companies but also some divisions of them. This also opens an interesting avenue for further research.”

Guajardoa et al. (2016) suggest: “The area is expanding rapidly and there are many interesting research opportunities. One is on the construction and management of the collaboration. A very important question is how to describe and measure the performance for different stakeholders in the collaboration. Another question is how to develop a process for different stakeholders to agree on a sharing mechanism and have the incentives to stay in it".

Cuervo, Vanovermeire and Sörensen (2016) say: "Horizontal logistic collaboration offers a great opportunity for companies to reduce their distribution costs. By forming a coalition and carrying out a joint operational plan, companies are able to achieve a larger profit."

"Opportunities for further research lie in exploring the effect of collaboration at all nodes of the SC. …the impact of the inventory policy can reduce costs" (Chan and Prakash 2012)

"As for further research directions, first, it is suggested to consider other assumptions in the considered supply chain to make it more practical, such as other kinds of inventory control policy" (Shafieezadeh and Sadegheih 2014).

It can be concluded, that there is a research gap in existing scientific articles regarding the collaborative logistics and inventory management. In addition, the cost allocation methods are not discovered to the largest scale, the problem of choosing a strategy regarding the payoff distribution is still not perfectly investigated. Thus, the topic of this master thesis "Cost allocation methods in collaborative logistics" is one of current interest and provides a strong interest in a research sphere.

In order to investigate the research gap to a fully extend, the EBSCO searching tool is also used. The search includes several key words, terms and full articles name. For more detailed and precise analysis, different key words are combined using "or" and/or "and" mark. The search results are represented in the Table 1.4

Table 1.4 Search results at EBSCO system

Key words	**Field**	**Search results (research journals)**
Logistics	Title name	37 847
Inventory management	Title name	5 963
Collaborative logistics	Title name	267
Collaborative transportation	Title name	195
Inventory EOQ	Title name	207
Collaboration (Collaborative) EOQ	Title name	0
	And	
Collaborative logistics	Full text	0
	Or	
Cost allocation	Full text	0

As the search result shows, the logistics and inventory management takes a lot of attention of researches and the topic is very popular. However, there are no scientific articles including the EOQ model and cost allocation mechanism. There are several articles about Inventory EOQ and several on collaborative logistics topic, but they are focusing on specific details (demand variations, shortage influence and planned shortage effect). The search results also show that there is a lack of articles describing Inventory EOQ model with cost allocation algorithm in collaborative logistics.

This lead to the main research question:

How can competing companies allocate costs from collaborative decision making in inventory management?

Conclusions of chapter 1

Supply chain term appeared about 40 years ago and now it is discussed a lot by the researches due to its versatility and complexity. Today supply chain management gains a lot of attention for the sake of its ability to affect the firm performance and customer satisfaction. To perform better, companies can improve SCM as a whole process or focus on its separate parts enhancement. Inventory management takes a significant part in companies' costs structure. That is why, efficient inventory system has a huge potential to influence the company's market position. Companies tend to apply different forms of inventory management strategies. However, existing ones are not obsolete and require constant improvement.

In order to save costs, meet the demand better, companies tend to collaborate on different levels – vertical or horizontal, the same level of supply chain or on exact segment of it. In this master thesis, the horizontal collaboration is discussed. This assumes managing across entire supply networks, even when they cross organizational or geographical boundaries.

The question of sharing the payoff from the collaborative game is not investigated to a fully extend. There is always some uncertainty regarding the distribution practice, incentive to stay or deviate from the coalition and duration of the collaboration practice. Moreover, there is a gap in the literature on the cost allocation mechanism for any number of players. Finally, the competing companies' inventory management collaboration is not examined, that creates research opportunities.

Chapter 2. Methodology

A methodology is a domain or a map, while a method refers to a set of steps to travel between two places on the map (Jonker and Pennink 2010). The process of collecting the data, analyzing it and preparing a report are three main parts of the methodology. In this chapter, the process of methodological study and applying different research methods for the problem are discussed. It also includes the description of the process from the choice of the methods, through the collecting data, analyzing it and ending with the results obtained.

2.1 Quantitative research methods

The data analysis can be made with two main kinds of methods: quantitative and qualitative. The main focus of the quantitative study is "to quantify data and generalize results from a sample to the population of interest; to measure the incidence of various views and opinions in a chosen sample; sometimes followed by qualitative research, which is used to explore some findings further" (Park and Park 2016).

2.1.1 Economic Order Quantity Model

Economic Order Quantity model is widely used in real life to manage the inventory and to find the order size. It is based on the condition that demand and supply have net effects. Demand is continuously occurring and inventory is continuously decreasing at a constant rate λ. It is assumed that the supplier has unlimited capacity of items and the leadtime L is constant. An assumption of the model is that the order size is always the same. Advanced model aims to find of the optimal order size, that eliminates the assumption of the lot size. The process of putting an order in the basic EOQ model is described on the Figure 2.1.1

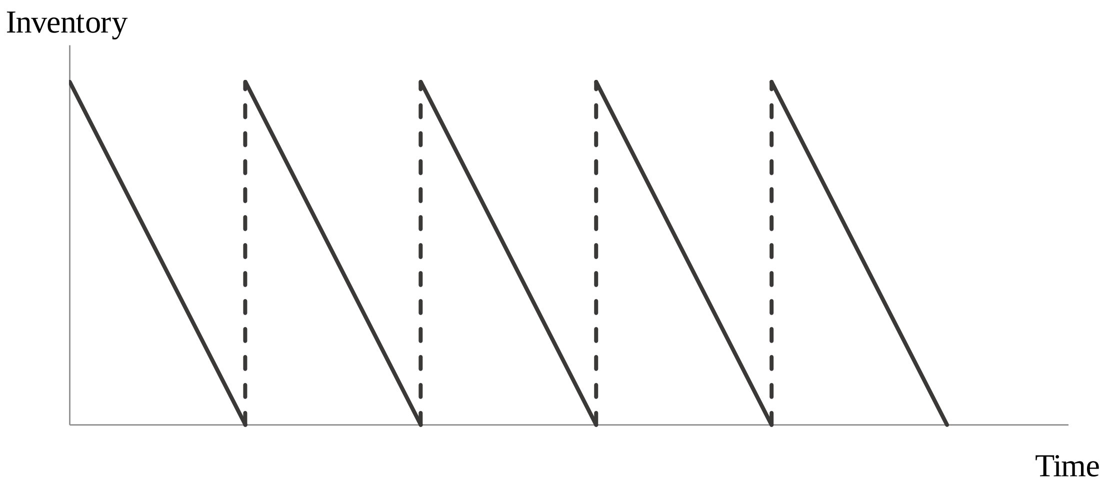


Figure 2.1.1 Basic EOQ model

Denote the demand during the leadtime equals (Wilson 1934):

$$D = \lambda L,$$

The total costs for one unit is:

$$C = c\lambda + k\frac{\lambda}{q} + \frac{hq}{2},$$

where c– variable costs to place an order,

λ - demand rate,

k - fixed costs to place an order,

q - order size,

h – holding costs.

In theory, the lines corresponding to the replenishment of stocks are vertical as they are gained immediately. In practice, the lines have a slope because in real life some time is spent on the unloading of trucks (whether by people or automatically) and moving goods to the warehouse.

2.1.2 Game theoretical approach

In this thesis, the game theoretical approach is used. According to Crawford (2016), game theory is “a precise and detailed language for describing strategic interactions and a set of assumptions for predicting strategic behaviour”. In this work, different assumptions are made and used to conclude and structure the findings.

Game theory helps to realise why some situations (combinations) take place and how they can be explained. The outcomes of the game theory are reasonably supported by facts and logical decisions.

A “game” can be described as a combination of four elements (Froeb and McCann 2008):

1. The players (companies and potential partners)
2. The rules that constrain the game (limits, regulations)
3. The set of decisions or choices a player makes (collaborate or not)
4. The payoff that comes from the choices made

Vincent Crawford (2012) also summarises the main aspects of the game. He states that the game can be characterized by players (who makes decisions in particular), their behaviour, knowledge and experience, resulting in a strategy (several decisions made during the process) that led to different outcomes – payoffs (utility for each player). According to John Nash (1951), a game can be zero-sum function. By this concept, he explained that in a game with two players, where one wins something, another loses the same utility volume. Thus, the sum of their payoffs results in zero. This idea had a huge impact on the development of game-theoretic concept and was fundamental one. That is why, introducing the concept of a game in this thesis, all necessary elements were identified.

2.1.3 Cooperative game, Core of the game and Shapley value

In a cooperative game with two or more players, there is always a question of how to share benefits. In a coalition, surplus distribution models assumed stable if they satisfy all the players and keep them in a coalition. In a game, the number of distribution variations between players are infinitely. In a theory, the Core is a solution concept that assigns to each cooperative game the set of payoffs that no coalition can improve upon or block (Serrano 2007). Feasibility of a solution means that it satisfies all the requirements and meet all the restrictions. Nevertheless, for some players or in some games, there is also an optimal solution.

Denote the allocation $\alpha=(\alpha_1,\ldots,\alpha_n)$ dominates the allocation $\beta=(\beta_1,\ldots,\beta_n)$ in a coalition $S\subset N$, where N – set of players, (represented as $\alpha \succ_S \beta$) if:

$$\alpha_I > \beta_I \text{ for all } i \in S,$$

$$\alpha(S) \leq v\,(S),$$

where $\alpha(S) \equiv \sum_{i\epsilon S} \alpha_i$

Condition $\alpha_I > \beta_I$ for all $i \in S$ means that distribution $\alpha=(\alpha_1,\ldots,\alpha_n)$ is better than the distribution $\beta=(\beta_1,\ldots,\beta_n)$ for all members of the coalition. Condition $\alpha(S) \leq v\,(S)$ reflects the feasibility of allocation $\alpha=(\alpha_1,\ldots,\alpha_n)$ by the coalition.

Multiple non-dominated distribution in a game is called the Core of the game (Petrosyan, Zenkevich and Shevkoplyas 2012). It is a suitable form to find feasible solution and agree on it in cooperation. However, one of the weaknesses of the Core is that it can be empty, meaning that not in every coalition there is a feasible solution to distribute surpluses or allocate costs between players and it can include a lot of variants (it is not unique).

The multiplicity of the Core and its emptiness motivated other authors to find distinct approach for the surplus distribution. Shapley value is a concept that creates a unique distribution of surplus generated by a coalition among coalition members equally (Shapley 1953). Given exogenous weights for all players, the corresponding weighted Shapley value distributes the dividends proportionally to their weights (Brink, Levínský and Zelený 2015).

2.1.4 Contemporary analytical studies

The concept of game theory always has a lot of attention of the researches. Authors used it to explain why some decisions were made even they did not seem to be rational or beneficial at first glance.

One of the research articles is the “Graphs and cooperation in games” by Myerson (1977). Among different research questions answered, one is “How will the outcome of a given game depend on the cooperation structure?” Another important idea of the publication (Myerson 1977) is that there are not only two possible variations of game cooperation – either all the participants cooperate with each other or a game may be noncooperative. Perry and Reny (1994) assumed a dynamic game where all players might make a step at any time and a payoff assumed to be a perfect equilibrium. Samuelson (2016) made a clear distinction between cooperative and non-cooperative games. “Noncooperative game theory assumes that players act independently, with the central question being whether a player can gain from a unilateral deviation. Cooperative game theory assumes that players can form coalitions, with the central question being whether a collection of players can find a (binding) allocation of the payoffs available to the coalition that would allow them all to gain from forming the coalition” (Samuelson 2016). Also, there are a lot of intermediate variations (coalition, connectedness).

Roger Myerson described the process of coalition partition about 40 years ago. He also suggested a model of how to allocate the benefits from the cooperation between parties. The main input is that in games links between partners may be represented as a graph. He explained the algorithm how to find the utility partition and explain the payoff difference. It can be found below (Myerson 1977).

$$\forall_{\mathrm{g}} \in \mathrm{GR},\ \forall \mathrm{S} \in \mathrm{N/g}\,,\ \ \sum_{\mathrm{n} \in \mathrm{S}} \mathrm{Y_n}(\mathrm{g}) = \upsilon(\mathrm{S}).,$$

where

GR – all possible cooperation graphs,

where υ - a game,

S – each coalition,

$\mathrm{N/g}$ – national coalition structure associated with cooperation graph g,

$\upsilon(S)$ - benefits firms gain and have to divide,

n – number of players,

$\mathrm{Y(g)}$ – utility payoff.

Concluding from the expression above, it is seen that for any graph g that belongs to the set of cooperation graphs GR that suits the restrictions, and for any coalition S belonging to the connectedness partition $\mathrm{N/g}$, the sum of utility payoffs of graphs g, where players n belong to the set S equal the characteristic function outcome.

The question of how to share the payoff of gained benefits is a core one in a collaborative logistics. The method of cost allocation should satisfy all the participants, be strong to keep all the parties in a coalition. It should be beneficial and thus make everyone willing to take part in a game. Due to this strong restriction, not every company wants to participate in a game.

The game theory described the principle of the Core of a game. The cost allocation may be assumed as one that lie within the Core, when it satisfies the following criteria (Petrosyan, Zenkevich and Shevkoplyas 2012):

$$v(s) \leq \alpha(s) = \sum_{i \in s} \alpha_i,$$

where

$v(s)$ – payoff of the coalition,

$\alpha(s)$– cost distribution for coalition s,

$\sum_{i \in s} \alpha_i$ – sum of all cost distributions of players i in a coalition s.

When all these conditions are satisfied, the Core of the game is stable. Thus, all the participants are willing to stay in a game and play fair. The condition of reaching the Core of the game with the minimum costs (Guajardo and Rönnqvist 2015) may be represented as following expression:

$$\sum_{J \in N} \left(\alpha_{j,k} \times \sum_{k \in K} U_{j,k} \right) \leq C_K \quad \forall k \in K,$$

where the left part of the equation represents the sum of all costs inquired by all the organizations in the coalition K, that is less or equal the cost inquired by all the companies in a coalition in a stand-alone form.

Cuervo, Vanovermeire and Sörensen (2016) determined the main characteristics that influence the collaboration practices and compared several combinations of coalitions of the companies. The features are: number of orders, average order size, maximum number of days an order can be delayed. They decided also to compare two patterns by changing the characteristics value.

The approach can be described as a collaborative result - the sum of stand-alone and coalition costs (Cuervo, Vanovermeire and Sörensen 2016).

$$P(A, B) = c(A) + c(B) - c(A, B),$$

where $P(A, B)$- coalition profit,

$c(A)$ – costs, inquired by firm A,

$c(B)$ – costs, inquired by firm B,

$c(A, B)$ – costs, inquired in a coalition.

The decrease in distance in km of each truck in an operational plan represents the gains from the coalition. Consequently, the less the value of the number, the higher the efficiency of the coalition.

The authors additionally count the percentage change in the stand-alone costs of the company to find out the level, an organization can reach within the partnership.

$$S(A, B) = \frac{P(A,B)}{c(A)+c(B)} \times 100,$$

where $S(A, B)$ – synergy effect from the coalition.

In the paper researches investigate the outcomes by calculating two these variables (P and S) for each possible combination they assume and comparing the performance.

One recent paper (Flisberg et al. 2015) is devoted to the cost allocation problem in coalitions with application on the real-world case study. The idea of the paper arose from the wish to find methods for lowering logistics costs. Özener, Ergun and Savelsbergh (2013) worked also on transportation costs and cost allocation mechanism.

The case study (Flisberg et al. 2015) is dedicated to the forest fuel transportation in Sweden. The situation with alternative fossils e transportation in Sweden can be described as a logistics process. There are more than 20 companies specializing in a wood fuel in Sweden. They are located in different areas and inquire a high transportation cost. In addition, seasonality and imported goods affect this sector. Current model of transporting these fuels assume that small companies transport fuel to the bigger producer and then it transports the mass to where they are needed. In order to change the model into more efficient one, some variants are possible.

The first suggestion proposed by the author (Flisberg et al. 2015) is to change the transportation chain according to the seasonality factor. For instance, change a month when the cargo is provided and thus save costs. Another option is to substitute some goods with another from different assortment groups. The third alternative is to collaborate with other plants. This will reduce spending, create more optimal routes and satisfy the customer with a higher speed. In the paper three main insights can be listed: a country-wide analysis of a sector, potential alternatives for saving costs and proposition of cost allocation models.

Regarding the transportation issues, the shorter the path of a track, the more efficient is the system. Thus, the planning and optimizing the route is vital for the whole supply chain. This can help to make the supply chain more efficient and to optimize spending.

The chart of the volume (in tonnes) transported in different distance classes for four forest biomass assortments is represented on the Figure 2.1.2 (Flisberg et al. 2015).

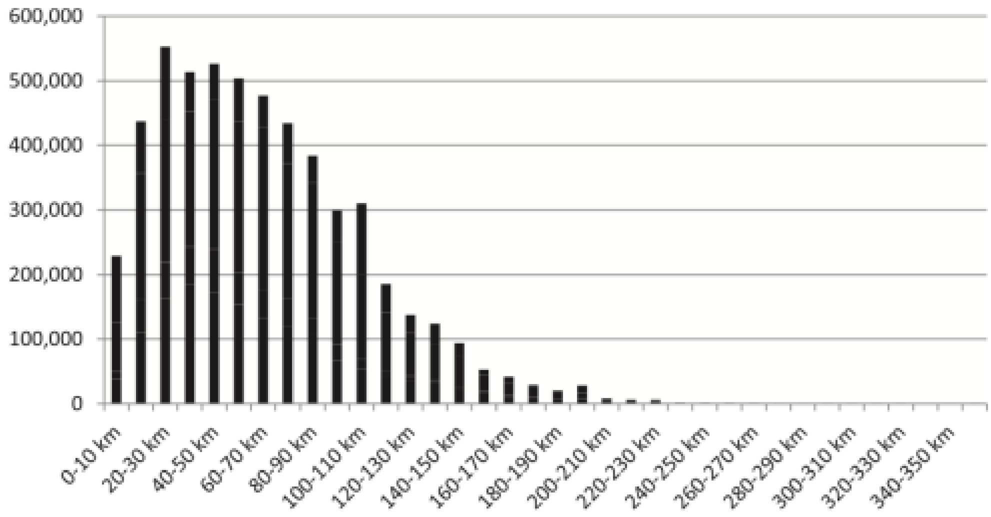


Figure 2.1.2 Volume in tonnes transported

It can be found in a paper that the average distance is 64,4 km. In order to estimate the optimal distance, the linear programming model may be applied.

$$\min C = \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{t\in T} C_{ijkt}X_{ijkt}$$

This function minimizes the total transportation costs for each supply point (i), the demand point (j), for each assortment group (k) and in each time period (t). However, it works sufficiently only with several restrictions:

a. all the amounts coming from the supplier point correspond to the available amount on each supplier points at a given time period t
b. the demand flow is satisfied for each assortment category at a given period of time
c. the inventory balance in each supplier should be kept
d. all the variables should be equal or more than 0

Another paper explaining the minimization of costs in stable cooperative Vechicle Routing Problem (VRP) is one by Zakharov and Shchegryaev. Authors developed a method to calculate subadditive characteristic function and update it for the dynamic VRP game (Zakharov and Shchegryaev 2012). Yengin (2012) characterises Shapley Value to apply it in fixed-route salesman problem.

All previous examples demonstrate that the question of playing together in a coalition is popular nowadays among scientists. While some researches focus on the savings and benefits from the cooperation, others improve the existing models and trying to solve the problems occurring from cooperation. However, on practice real companies use not all of the approaches. This mean, that there is a lack of practical models helping business.

2.2 Qualitative research methods

Qualitative research methods and techniques consisting of many options for researchers to employ. Some include case study research, ethnography (in-depth interviews, and participant observation), netnography (online ethnography) (Kozinets 2002). The main goals of the qualitative methods are to understand the underlying motives and reasons, generating hypothesis and preparing trends for future quantitative analysis (Park and Park 2016).

2.2.1 Case-study

In order to apply the model that is going to be discussed later, several cases of real companies are examined. The main goals of this approach are to obtain multiple perspectives on process and practice and to discover why this process is happening. Case study is relevant research that contributes to the influential study (Eisenhardt and Graebner 2007).

A research method that facilitates a deep investigation of a real-life contemporary phenomenon in its natural context is a case study (Woodside 2010; Yin 2012).This approach also helps to validate the practical importance of the theory and discover what works well and what can be improved. It helps to look on things from different perspectives and compare theory wit practice. Thus, any findings or conclusions are likely to be more compelling and accurate (Yin 2003).

2.2.2 Secondary data

In order to conduct the analysis, secondary data is used. Official reports of several consulting companies are examined and observed. Reports were chosen based on several factors. The main preconditions are that documents contain all necessary information regarding the real estate rates and dynamics, commercial real estate players and statistic data. Secondary sources are valuable for the analysis and evaluation of variables value needed to validate the method proposed on practice.

2.3 Developed theoretical framework: symmetric case (demand is equal for players in a coalition)

Let assume the model, where similar products are storaged in one warehouse by different competing companies. In order to obtain benefits, they might collaborate and agree on cost allocation mechanism. In order to do this, an Inventory Cost allocation in collaboration (ICAC) method is proposed.

We consider products similar when it is a homogeneous group, its demand rate is stable and predictable, do not depends on the season, the price for goods are in the same price category and the storage conditions are identical. The good example of the groups we are going to discuss is sugar, flavor, soft drinks, dishwasher and washing machine powder, furniture and computer hardware.

Denote

q– order size.

q^*– economic order quantity, i.e. optimal order size, minimizes total cost per time unit.

Following from the basic EOQ model, the optimal order size $q^*$for two players – Player 1 and Player 2- should be:

$$q_1^* = \sqrt{\frac{2k\lambda}{h}};\ q_2^* = \sqrt{\frac{2k\lambda}{h}},$$

where k – fixed costs, that include administrative, transportation and receiving the order expenditures,

λ - demand rate, in this model we assume it is the same for each player because the products are homogeneous,

h – marginal holding costs, that include inventory (storage, insurance, refrigeration) and rental costs as well as the costs that depend on the product unit price because money invested in stock may be deposited.

The costs of each player if they act along equals:

$$C_1 = \sqrt{2k\lambda h};\ C_2 = \sqrt{2k\lambda h};$$

The sum of the costs:

$$C_1 + C_2 = 2\sqrt{k\lambda h};$$

In the ICAC model, it is assumed, that the demand rate and the fixed costs for products do not differ significantly, the holding costs are equal due to the usage of the same warehouse.

Thus, the order size for both players equals:

$$q_{1,2} = \sqrt{\frac{2k2\lambda}{h}};$$

And the costs inquired by each player can be represented:

$$C_{1,2} = \sqrt{2k2\lambda h} = \sqrt{2}\sqrt{2k\lambda h};$$

From these assumptions, it can be noticed that the total costs of players in both scenario differ – playing alone require higher total spending comparing with the scenario of acting together.

Continuing discussion of the model, let assume the set of all players as S and consider game-theoretical approach.

$$S = \{1,2,\dots,S\};$$

Then the order size for the set of players in this game should equals

$$q_s = \sqrt{\frac{2kS\lambda}{h}},$$

and the costs enquiring by each player in the game should be:

$$C_s = \sqrt{S}\,\sqrt{2k\lambda h}.$$

This follows from the equation above, that with the increased number of players, the total costs for each player decrease.

Assuming the number of players, it is denoted that

$|S| = s, |T| = t, S \cap T = \emptyset$:

$$C_s = \sqrt{s}\sqrt{2k\lambda h};\ C_T = \sqrt{t}\sqrt{2k\lambda h};$$

$$\sqrt{s}\sqrt{2k\lambda h} + \sqrt{t}\sqrt{2k\lambda h} - \sqrt{s+t}\sqrt{2k\lambda h} = \sqrt{2k\lambda h}\left(\sqrt{s} + \sqrt{t} - \sqrt{s+t}\right) > 0;$$

It means that the total costs for players playing together equal or less the total costs when they play apart.

$$C_s + C_T \geq C_{S\cup T};$$

Following this idea, it should be stated that total costs inquired by players if they act together equal or even lower than the costs if they act alone. This means that the synergetic effect is achieved.

Consequently, cost function for a coalition is subadditive and it is a motivation for players to cooperate to save cost. As a result, a cooperation game $\Gamma = \langle N, C\rangle$ is defined. For such a game, it is shown that Core is nonempty and Shapley value belongs to the Core.

Let assume for the arguments to be more readable, we have a finite set of players α, denote an imputation $\alpha = (\alpha_1, \dots, \alpha_n)$, where α_1 – part of total expenses $\sqrt{n}\sqrt{2k\lambda h}$, that a player i pay, thus the costs for the set of players equal:

$$\alpha_1 + \alpha_2 + \cdots + \alpha_n = \sqrt{n}\sqrt{2k\lambda h};$$

let the player's costs be taken as equal $\sqrt{2k\lambda h} = \gamma$;

$$\alpha_1 + \alpha_2 + \cdots + \alpha_n = \sqrt{n}\,\gamma$$

Simultaneously, the principle of individual rationality must be fulfilled. This mean that each of players while allocating costs α in cooperation, should spend no more than if he acts alone.

$$\alpha_i \leq \gamma$$

Let us investigate if the Core is not empty. Due to the symmetry of a game (the costs are equal), the conditions of Core existence take the form:

$$\begin{cases} \alpha_i \le \gamma \\ \alpha_i + \alpha_j \le 2\gamma \\ \ldots \\ \sum_{i=1}^{n-1} \alpha_i \le \sqrt{(n-1)}\,\gamma \\ \sum_{i=1}^{n} \alpha_i = \sqrt{n}\,\gamma \end{cases} \qquad (1)$$

This can be easily investigated and the system (1) has a solution in a form:

$$\alpha_i = \frac{\sqrt{n}}{n}\gamma$$

consequently, the Core exists. Thus, it can be proposed to find the Core and negotiate on the stable cost allocation mechanism. In this master thesis, “stable” and “sustainable” cost allocation stands for such a distribution, that satisfies all the players of the game, keeps them in a coalition and makes any deviation economically unprofitable. One of the existing model for cost allocation is Shapley Value that has some advantages comparing to the Core. Firstly, it always exists, while the Core may be empty. Next, it proposes the unique distribution that is stable. The Core can have multiple stable allocations and the player can inquire different costs in different coalitions that contribute to the deviation incentive. However, the most prominent decision is to use Shapley Value that is located within the Core. Because if the Core is empty, even the Shapley value is not stable as a cost allocation model.

Consider the following statement: The ICAC method has a cost allocation mechanism that is Shapley Value located inside the Core. Mathematical calculations and proofs presents in Appendix 1. This means that the decision has a motive for companies to cooperate, it is stable and creates a compromise for each party in a game.

The ICAC method also changes the order size, order frequency and the stock level. This happens because the demand of several players involved in a coalition is aggregated and the stocks that are available when needed are kept in a shorter period.

For the symmetric method, the order size for each player acting alone equals:

$$q_1^* = \sqrt{\frac{2k\lambda}{h}};\ q_2^* = \sqrt{\frac{2k\lambda}{h}},$$

The total order size for both of them is

$$q_{1,2} = \sqrt{2}\sqrt{\frac{2k\lambda}{h}},$$

The ratio of order sizes for 2 players is

$$\frac{q_{1,2}}{q_1 + q_2} = \frac{\sqrt{2}\sqrt{\frac{2k\lambda}{h}}}{2\sqrt{\frac{2k\lambda}{h}}} = \frac{\sqrt{2}}{2} = 0{,}71$$

The ratio shows that the total order size is less than 1. If the number of players in a coalition increases, the ratio decreases and its result equals percentage changes in the order size. For 3 players, for example, it equals $\frac{\sqrt{3}}{3} = 0{,}58$ (decreases by 100-58=42%), for 4 players is equals $\frac{\sqrt{4}}{4} = 0{,}5$ (decreases by 50%). The graph of the order size changes can be represented as a hyperbolic function. For easier representation, let us take an order size equal to 1500 and see the changes corresponding to the changes of the number of players. It is shown on the Figure 2.3

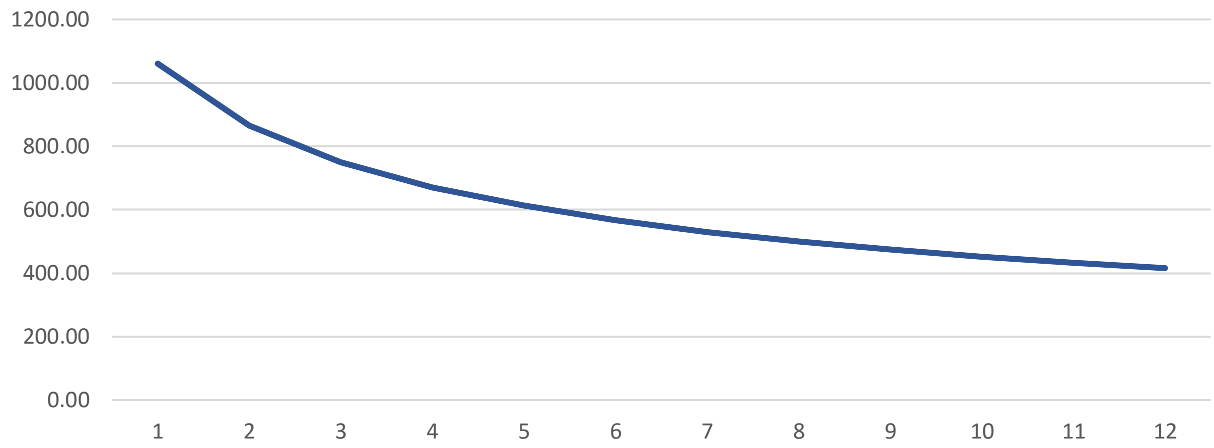


Figure 2.3 Order size changes depending on the number of players in a coalition

It can be seen from the figure above, that the order size is decreasing with the increase in number of players. This is beneficial for companies because they will order less with the ICAC implementation, inventory level will decrease and the holding costs will be less. Moreover, less people may be responsible for the placing orders and thus, the fixed costs are decreasing.

2.3 Extended framework: asymmetric case (demand is not equal for players in a coalition)

Despite the advantages of the ICAC method, the real-life cases show that the parameters value may be different for different companies. The holding costs h may vary because of different types of relationship between tenant and Landlords, their intimacy and bargaining power of different players. The fixed costs to place an order k may vary significantly due to the types of decision making process in a company. When decisions are made centralized, less people are responsible for it comparing to the decentralized planning procedure. The salary of employee of one company can deviate from salary of another employee on the same position of another company and thus change the k value. Finally, the demand rate λ of several companies can be divers. This may happen not only because of the demand fluctuations, different price category of the products, but also because of the size of retail chain, number of supermarkets and difference in number of customers.

For this reason, extended framework is proposed. In this master thesis, the different demand rates λ of companies are examined. This helps to change the direction of the method make it more practical-oriented. However, the method now assumes only 2 players.

Let assume the coefficient a that will equate different λ.

$$\lambda_1 = a\lambda_2,$$

where λ_1- the first company's demand rate;

λ_2- the second company's demand rate,

a – coefficient that equalizes the difference in demand rates.

For instance, if the difference in demand rate is caused by the difference in market share, then in this equation the market share of one player is a time higher than another one.

Assuming the demand rate for the 1st company higher, Then, the costs inquired by each player in a coalition equals:

$$C_1 = \sqrt{2ka\lambda h} = \sqrt{a}\sqrt{2k\lambda h};\ C_2 = \sqrt{2k\lambda h};$$

The total costs of two companies playing alone equals:

$$C_1 + C_2 = (1 + \sqrt{a})\sqrt{2k\lambda h};$$

By joining capacity, playing together, the total costs will take form:

$$C_{1,2} = \sqrt{2k(1 + a)\lambda h} = \sqrt{(1 + a)}\sqrt{2k\lambda h};$$

In order to examine our method cost function, the principle of subadditivity is validated. The fact that total costs of playing alone is no less than the total costs of a coalition is checked.

$$C_1 + C_2 \geq C_{1,2}$$

In Appendix 2, the calculations and proof of the subadditivity principle may be found.

Now the method assumes different demand rates and still has the subadditivity characteristic. The total costs of players of alone games are higher than the total costs of the coalition. This means that the intention to collaborate.

The cost allocation in such a game is not equal. The difference in demand rates is leveled by the costs inquired. The Shapley Value helps to allocate the costs. Calculations maybe found in Appendix 3.

The order size also changes. Now, the order size for players equal:

$$q_1 = \sqrt{a}\sqrt{\frac{2k\lambda}{h}}$$

$$q_2 = \sqrt{\frac{2k\lambda}{h}}$$

The total order size for the coalition takes form:

$$q_{1,2} = \sqrt{1+a}\sqrt{\frac{2k\lambda}{h}}$$

This extended method is helpful to go deeper inside the difference in demand rate. The approach assumes difference because of the market share, number of supermarkets available and assumes equal intensity of the demand within one product category. Moreover, the method can be applied on different one-product categories within on company. For example, X5 retail group has different supermarkets for different market segments: Perekrestok, Pyatorochka and Karusel. The demand for one product within these supermarkets can be different, but the inventory is kept at the same warehouse.

2.4 Limitations of the framework

Due to the fact that the ICAC method based on EOQ model principles, there are some continuously assumptions and restrictions. The first assumption is that demand occurs continuously at a constant rate. As a result, inventory decreases at a constant rate λ. In practice, however, the demand is not so stable and can vary significantly according to the period, seasonality, supply instability or other external factors. In real life, some periods of totally zero demand may occur, meaning that the λ may be intermittent. For this reason, the extended framework is proposed. However, the extended method assumes the coalition and cost allocation for only two players. The bigger number of players as well as difference in other variables can be a source for further improvements.

Another important assumption the model based on is that the leadtime L does not depend on time or the order size. Contrary, the leadtime differs noticeably in appliance with not only time or order size, but also according to company's relationship with the supplier, product type and location of the buyer and supplier.

Thirdly, the inventory replenishment occurs immediately. However, delays, order cancelation and other issues are possible on practice. In addition, the process of unloading tracks, moving everything to the pallets and putting it on the shelfs takes time. Thus, the inventory jump up is another limitation.

Moreover, the stockouts are forbidden at this model. It is denoted that our inventory level is always enough to meet the demand. However, the process of inventory control in many cases is not perfect. The stockouts may be a result of inappropriate inventory management, unpredictable delays and human mistakes. Thus, to make the model more real, the stockouts may be assumed.

Finally, the time frame when we get the order is very narrow so that we receive orders exactly at the moment we need them. This means that we do not have any surplus in inventory or excess stocks somewhere else. On the other hand, the omissions and mistakes can be a source of surplus generated in inventory, that should be also examined.

Conclusions of chapter 2

The Economic Order Quantity model is widely used nowadays by companies for inventory control and management. It helps to determine the optimal order size and time when to place the order. However, the basic model has some assumptions and limitations that can be improved or adopted.

When company collaborate, a game-theoretical approach can be applied in order to manage the payoff distribution, cost allocation and explain the rational behaviour of player. There are several restrictions that determine it:

- the payoff of the game should be equal or higher than the sum of values of every player acting alone
- the costs inquired by each player should not be higher than the costs of playing alone.

When all the assumptions of rational behaviour are met, the Core of the game may be found. The core of the game is such a distribution of utilities, when every member of a coalition is willing to stay in it and has no incentive to deviate from the coalition. This distribution is called stable. However, the Core has some limitations: it can be empty (meaning there is no stable variation) and in can be multiplex (different combinations have different values for a player).

That is why there is one more method helping to allocate the gains or distribute the costs from the game between partners. It is called Shapley Value and distributes the payoff among players according to the value they bring to the coalition. Shapley Value has some advantages comparing to the Core of the game. It always exists and it is stable. In this master thesis, the distribution of costs is examined. The most effective distribution method, however, is one that is Shapley Value located inside the Core of the game. In the method proposed, the decision of cost allocation is located within the Core and is a Shapley Value.

For inventory management and cost allocation in a coalition, the ICAC method is proposed. It is based on the EOQ principles, assumes the collaboration between competitors and includes stable cost allocation mechanism that is Shapley Value inside the Core of the game. The extended framework assumes different demand rates because of the difference in market shares. However, the extended method with different demand rates is only suitable for the coalition of two players. Nevertheless, the method is appropriate for any companies suiting the restrictions.

Chapter 3. Cost allocation model. Case-study on Saint-Petersburg market

3.1 Description of cases

3.1.1 Case selection process

In this master thesis, a method ICAC for cost allocation from collaboration on inventory level is proposed. In order to examine the method's practical implication, it is being applied to real cases of retail companies. While looking for examples, several preconditions and restrictions were formulated. The main key words for the reports and data needed were: commercial warehouse property, public warehouse, warehouse rent, sharing warehouse capacity. As a result of the deep investigations, five reports were chosen for further reduction.

The first report is called "Marketing research of the market of commercial warehouse real estate of Krasnoyarsk 2014-2017" and is prepared by BOSgroup. The company is a marketing agency that focuses on marketing research and business planning. The main structure elements of the report are tendencies of the market of commercial real estate, demand and prospects evaluation of the warehouse business, profiles of the largest warehouse terminals in Krasnoyarsk and detailed description of the customers of it (retail hypermarkets). Despite the fact that this exact report contains all necessary information, the decision to look on Saint Petersburg market was made. The main reason is closeness to the users and service providers, that can be interviewed if needed and better understanding of the geography (location of terminals. roads and infrastructure).

Other reports that were found were issued by S.A. Ricci. It is a leading consulting company on the market of commercial and residential elite real estate in Russia. The reports the company prepares can be divided into five categories: offices, warehouses, trading business, real estate and consulting. The warehouse category was chosen among others. One of the most appropriate reports was "The review of the warehouse and industrial real estate market for 2016". It keeps the focus on Moscow region and provide statistical data regarding the tendencies, changes and forecasts on the warehouse market in 2016. S.A. Ricci also describes demand and supply ration. However, the same factors as in the previous example (geography trends and he distance between users and terminals) played a crucial role in order to continue the search.

JLL - the leading company in the market of professional services in real estate and investment management. Several reports prepared by it were found. It quarterly examines St. Petersburg Warehouse Market and issue official reports that are well structured and present the information regarding deals volume, existing players on the market, spots available for rent and distribution by location. However, they provide data that is in the finance sector not including the tenants of the terminals, demand and supply rated on the warehouse market. But, it includes the prices for renting main premises.

The fourth finding were reports by Colliers International - an international consulting company that provides a full range of services in the field of commercial real estate. The reports are published quarterly and include statistics of rental rates, trends and forecasts on industrial and warehouse markets in Saint Petersburg. Moreover, the major players on the market are also indicated. That is why these reports are considered crucial and are taken into further consideration.

Finally, the fifths report is one prepared by Knight Frank – a player in the commercial and elite residential real estate market in the North-West region. The reports are issued quarterly and reflect the supply and demand dynamics, commercial terms and main players. Considering this data, the reports are counted as significant and are used in the next steps of the master research.

The comparing analysis of different reports are provided in the Table 3.1.1

Table 3.1.1 Comparing analysis of the cases

No.	**Report**	**Prepared by**	**Geography**	**Chosen for the next stage**
1	Marketing research of the market of commercial warehouse real estate of Krasnoyarsk 2014-2017	BOSgroup	Krasnoyarsk	No
2	The review of the warehouse and industrial real estate market for 2016	S.A. Ricci	Moscow region	No
3	St. Petersburg Warehouse Market	JLL	St. Petersburg	No
4	St. Petersburg Industrial market/ St. Petersburg Warehouse market	Colliers Int.	St. Petersburg	Yes
5	Warehouse market report	Knight Frank	St. Petersburg	Yes

3.1.2 Description of the cases chosen

As a result of deep analysis of reports found, two major reports were chosen. The first is St. Petersburg Industrial market by Colliers Int., second - Warehouse market report by Knight Frank. Both of them contain the data from 2016.

3.1.2.1 St. Petersburg Industrial market by Colliers Int.

This report represents the main aspects of Saint Petersburg Industrial Market. One of important analysis conducted is a distribution of tenants (Colliers Int. 2017). It is represented on the Figure 3.1.2.1.

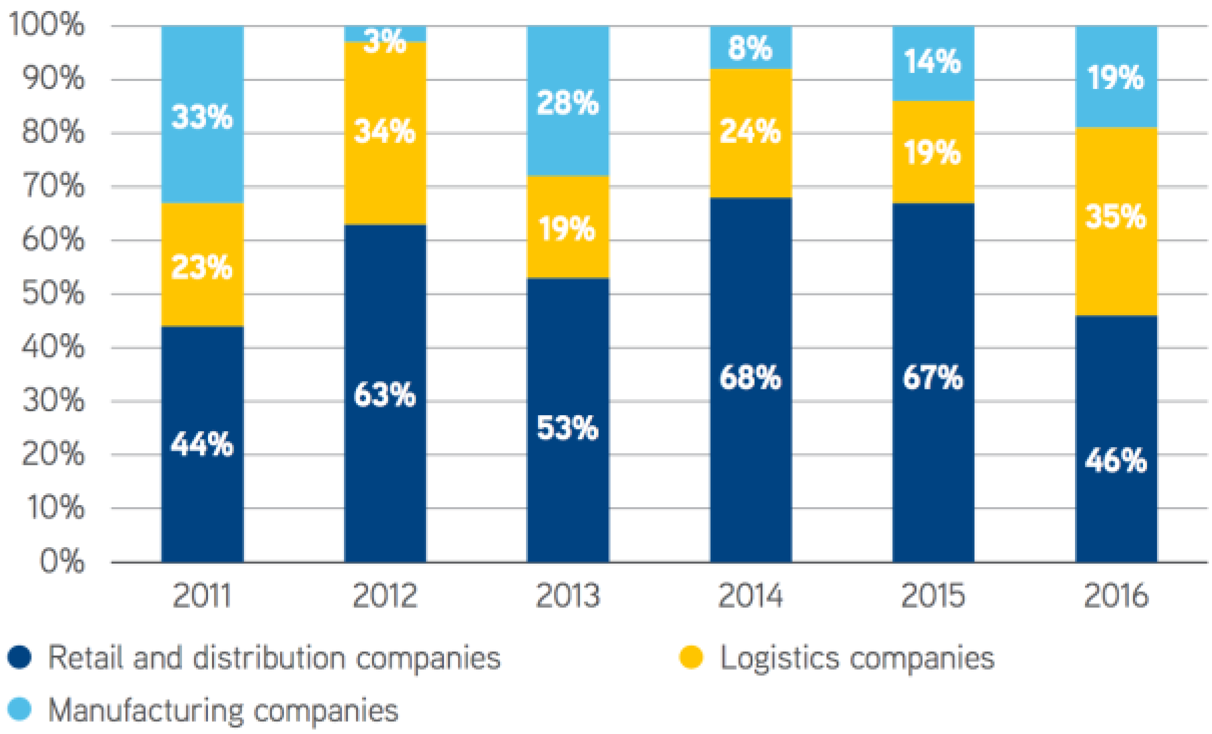


Figure 3.1.2.1 Demand for commercial real estate (warehouses) in Saint Petersburg and Leningrad region

From this graph it can be seen, that almost the half (46%) of all renters are retail companies. In previous years, the percentage of retail companies were higher. However, this does not mean that the demand felled. The reason can be in an increased number of Logistics and Manufacturing companies that changed the ratio of tenants. Following the high ratio of retail tenants, it can be concluded that the business model of many retail chains assumes renting warehouse or distribution centre. From this, the need for managing inventories effectively can be predicted.

Moreover, the report contains key market indicators, that are helpful for understanding of such numbers as rental rate, total stock and completions that are needed to apply the ICAC method. The data is represented in the Table 3.1.2.1

Table 3.1.2.1 Key market indicators

Key market indicators	**2015**	**2016**
Total stock, million sq. m.	2,59	2,78
Completions, thousand sq. m.	183	189
Take-up, thousand sq. m.	226	200
Vacancy rate, %	6,9	4,4
Average rental rate, RUB/sq.m./year	4 200	4 000
Here, rental rates are given excluding VAT, OPEX and utilities		

According to the data in the report (Colliers Int. 2017), the rental rate is equal to 4000 rub. per year. This data will be used in calculations later.

3.1.2.2 Warehouse market report by Knight Frank

Another report that is used to apply ICAC method is one prepared by Knight Frank. It represents supply dynamics of different classes of warehouses, and shows that supply is growing since 2013 and accordingly the demand does. For the ratio and dynamics see Figure 3.1.2.2.1 (Knight Frank 2017)

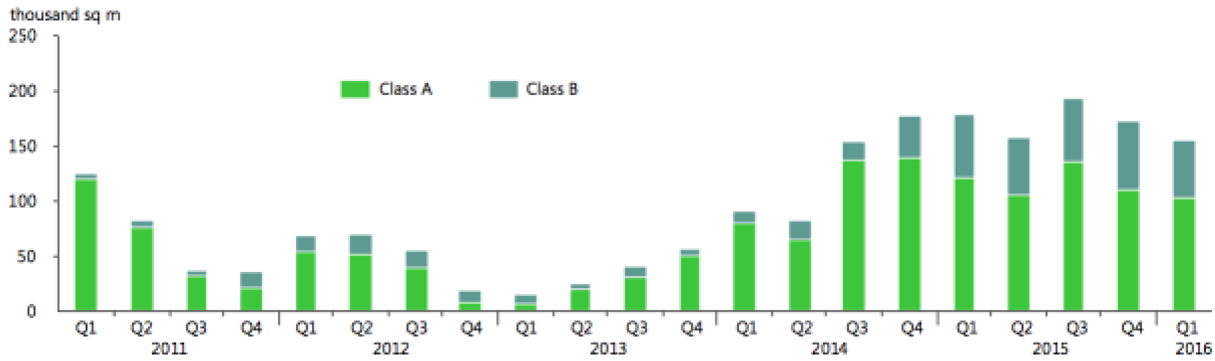


Figure 3.1.2.2.1 Supply Dynamics by Classes

Furthermore, the information of geographical distribution can also be found in the report. According to the study, most of the warehouses are located on the South or South-East and South-West part of Saint Petersburg. Because the distribution is extreme, it can be assumed that a lot of companies are located in one part of the city close to each other that makes it easier to find real examples for the method applying. The diagram of geographical distribution (Knight Frank 2017) is presented on the Figure 3.1.2.2.2

Figure 3.1.2.2.2 Geographical distribution of demand, 2017

Prior 2015, the asking rental rate has been declining, now it stabilized. The difference comes from the exchange rate fluctuations. "The average asking rental rate of 2016 was 76 $/sq m/year in Class A and 65 $/sq m/year in Class B, including OPEX, net of Vat." (Knight Frank 2017).

This means that the prices stop falling and companies cannot wait for the depreciation. They have to search for another solution to decrease costs. The asking rental dynamics is shown on the Figure 3.1.2.2.3

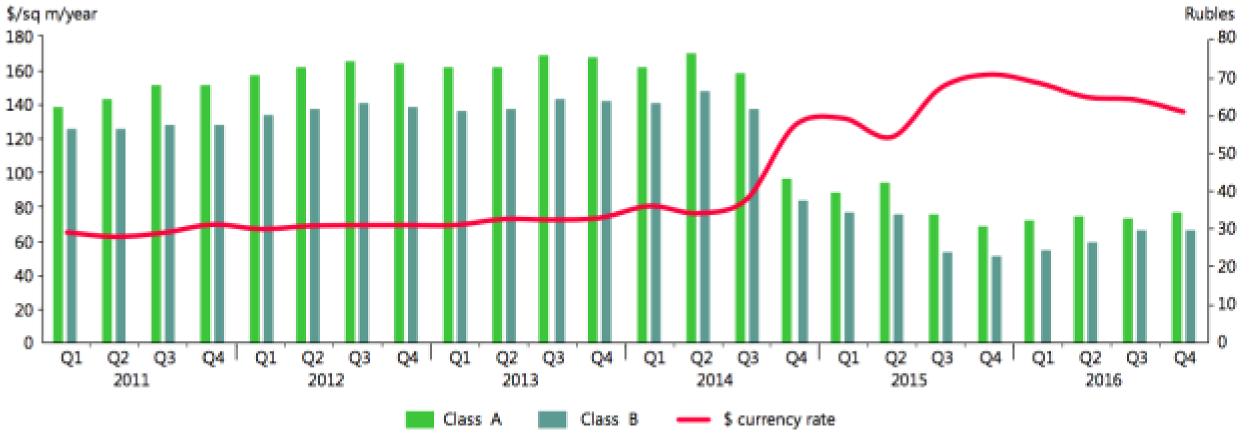


Figure 3.1.2.2.3 Asking rental rates dynamics

Finally, the practical data about real case examples can be found in this exact report (Knight Frank 2017). The key properties delivered are shown in the Table 3.1.2.2.1

Table 3.1.2.2.1 Key properties delivered in 2016

Property	**District**	**Class**	**Warehouse Space, thousand sq. m**
Magnit (2nd phase)	Tosnensky	A	34.2
St. Petersburg – south Distribution centre of X5 retail group (armada park)	Pushkinsky	A	27.9
Novosel'e Business park	Lomonosovsky	B	27.5
A Plus Park Saint Petersburg-1 (Auchan)	Pushkinsky	A	23.5
A Plus Park Saint Petersburg-1 (AkM-2)	Pushkinsky	A	21.0
Ulmart, Suburban Fulfilment Centre	Krasnogvardeisky	A	18.5

It can be concluded that two major competitors – X5 retail group and Auchan is renting the same terminal in Pushkinsky district of Saint Petersburg. Moreover, according to the X5 retail group report, the main players on Russian market correspondingly to the net retail value and share in the volume of 10 leading companies are Magnit, X5 retail group and Auchan respectively. That is why, for these retail chains, the ICAC method can be easily applied. For this reason, the rental rates for the square kilometer of the warehouse they rent are needed and taken for the future investigations.

In order to compare the data from different reports, dynamics indicators are also taken from the reports and analyzed. It is helpful for clearer understanding of what is the market key factors, what is the dynamics and how this can be used. The data (Knight Frank 2017) is represented further in a Table 3.1.2.2.3

Table 3.1.2.2.2 Key indicators. Dynamics against the 2015

Index	**Class A**	**Class B**
Total quality stock, thousand sq. m.	3,106 ↑	
Including, thousand sq. m.	1,988	1,118
New delivery in 2016, thousand sq. m.	252↑	
Total quality stock for lease, thousand sq. m.	1,7355↑	
Total vacant supply, thousand sq. m.	180↑	
Take-up for 2016, thousand sq. m.	243↑	
Vacancy rate, %	4,9↓	7,3↑
Average asset-by-asset change of the rent in rubles, %	-7	-2
Asking rental rates, $/sq. m./year, including OPEX, net of Vat (18%)	69–89	48–80

Comparing the asking rental rate estimated in Knight Frank and Colliers International reports, prices match each other. The price is close to 4000 rub/sq.m. or 70$/sq.m.

3.2 Practical implication of the method

Investigating the above-described reports, X5 retail group and Auchan supermarket has been taken as examples of competitors that are renting the same terminals out. Because both of them are hypermarkets, the assumption that both retail chains sell homogeneous products demand for which are stable and predictable is made.

X5 retail group is the second biggest retail chain in Russia. Its annual turnover in 2016 was 1,033,667 mln. rubles. Auchan is the third market player in Russia.

Following the basic of EOQ model, he optimal order size q^* for two players – Player 1(X5 retail group) and Player 2 (Auchan) - should be:

$$q_1^* = \sqrt{\frac{2k\lambda}{h}};\ q_2^* = \sqrt{\frac{2ka\lambda}{h}},$$

where k – fixed costs, that include administrative, transportation and receiving the order expenditures,

λ - demand rate for X5 retail group,

$a\lambda$ - demand for Auchan,

h – marginal holding costs, that include inventory (storage, insurance, refrigeration) and rental costs as well as the costs that depend on the product unit price because money invested in stock may be deposited.

Due to the fact, that both companies store their inventory in the same warehouses, the holding costs h, as well as the λ - demand rate, are assumed to be equal because we compare homogeneous products and the demand are stable and equal. Fixed costs are difficult to estimate for any company, but here they are count.

In our examples, h equals to annual asking rental rate that is 4000rub/sq.m. In this example, the costs for sugar is examined. The capacity of euro pallet is 1600 packages of 1kg. sugar and the number of pallets in the warehouse we examine can be up to 4. We evaluate the number of packages per 1 sq.m. as it equals to 3200. The dimensions of euro pallets widely-used nowadays is 1,2m x 0,8m, meaning that the square is 0,96 and is very close to a representation of 1 sq.m. In order to examine annual demand for the sugar of retails companies in Saint Petersburg and LO, the next formula is chosen:

$$\lambda = \text{annual sugar consumption per person} * \text{population of St. P and LO};$$

For the annual demand evaluation of chosen retail chains, the market shares of chosen retail channels are taken. According to the X5 retail group annual report, X5 retail group takes 6.2% of the Russian market, Auchan – 2.5%. It is assumed, that the ration of market share is the same for Saint-Petersburg and Leningrad region. For the sake of demand rates validation, the next formula is used:

$$\lambda = \text{annual sugar consumption per person} * \text{population of St. P and LO} * \text{market share};$$

The market shares are takes equals within the whole Russia. According to Rosstat data, annual consumption per person in Saint Petersburg and Leningrad region equals 40kg. The population of Saint Petersburg and Leningrad Region is 10mln. Thus, the annual consumption of sugar equals 40mln. In order to estimate the ratio of 1kg. packages of sugar within all other variations, the assumption that it takes 55% is taken. It is assumed, that a lot of families in

Leningrad Region buy bigger packages and in Saint Petersburg people may buy another types of sugar (crystlized) or even sweeteners. It means, that in Leningrad Region and Saint Petersbur, total demand for sugar equals 220 000 000 packages of 1 kg. Annual demand for X5 retail group in Saint Petersburg λ_1 = 13 640 000 packages that weight 1kilo, for Auchan λ_2 = 5 500 000 packages. Total annual demand for both retail chains equals λ = 19 140 000 packages of 1kg. sugar.

As for the fixed costs, they can be calculated as product of employee that works in planning and purchasing department and their salary divided by the number of orders per year. According to the personal analysis of the market of retail channels of FMCG type, for sugar (as well as for other product categories that can be stored) the bidding procedure once or twice per week is held. This mean, that only 1 person in each retail channel is responsible for bidding for the exact volume of products needed and placing an order. The average salary for the position in Saint Petersburg and Leningrad region is 80 000 – 100 000 rub/month. In this example, the salary equals 90 000. Finally, it is discovered that because biddings are held every week, annually around 52 orders are placed for grocery products. Thus, the fixed costs for each company equals:

$$\mathrm{k} = \frac{1 * 90\ 000 * 12}{52} = 20769,23 \text{ rubles per year}$$

Because the market shares of X5 retail channel and Auchan is different, annual demand rate is different as well. This means, that the extended method ICAC should be used in order to calculate the costs inquired in a coalition and then allocate them. The costs of each player if they act along equals:

$$\mathrm{C}_1 = \sqrt{\mathrm{a}}\,\sqrt{2\mathrm{k}\lambda\mathrm{h}};$$

$$\mathrm{C}_2 = 1\,\sqrt{2\mathrm{k}\lambda\mathrm{h}}$$

where a – coefficient that equalizes the demand rates of different players.

$$\lambda_2 = \mathrm{a}\lambda_1$$

In this method, the difference in demand rates is estimated as once resulting from different market shares. In order to find coefficient a value, the ratio of market shares should be found. Dividing X5 retail Group market share to the Auchan market share a = 2,48. For Auchan a = 1.

$$\mathrm{C}_\mathrm{A} = \sqrt{1}\sqrt{2 * 20\ 769{,}23 * 5\ 500\ 000 * 1{,}25} = 534\ 393{,}97 \text{ rub/year}$$

$$\mathrm{C}_{\mathrm{x}5} = \sqrt{2{,}48}\sqrt{2 * 20\ 769{,}23 * 5\ 500\ 000 * 1{,}25} = 841\ 564{,}47 \text{ rub/year}$$

The sum of the costs for both players:

$$C_1 + C_2 = (1+\sqrt{a})(\sqrt{2k\lambda h}) = 1\ 375\ 958{,}45\ \text{rub/year}$$

This means that the total costs per year for these 2 supermarkets equal 1,37 mln. rubles. However, by applying the ICAC method, the costs are reduced and the surplus is generated. By joining capacity, playing together, the total costs will take form:

$$C_{A,X5} = \sqrt{(1+a)}\sqrt{2k\lambda h};$$

$$C_{A,X5} = \sqrt{1+2{,}48}\sqrt{2*20\ 769{,}23*5\ 500\ 000*1{,}25} = 996\ 899{,}03\ \text{rub/year}$$

By building a coalition, the costs for storage the products are equal 996 899,03. rub/year Comparing to the total costs of a game if players act separately (1,37 mln. rubles), the surplus generated equals 379 059,41 rubles.

Due to the fact that the demand rate of X5retail group and Auchan differs, in order to allocate costs among players, a new formula proposed cannot be used. The costs for the exact player cannot be found by the ICAC formula:

$$\alpha_i = \frac{\sqrt{n}}{n}\sqrt{2k\lambda h}$$

For the cost allocation in a method with different demand rates, the Shapley Value is used. The costs inquired by each retail chain analyzed equals:

$$\vartheta_{x5} = \frac{\sqrt{2k\lambda h}}{2}\left(\sqrt{a}+\sqrt{1+a}-1\right) = 652\ 034{,}76\ \text{rub/year};$$

$$\vartheta_{A} = \frac{\sqrt{2k\lambda h}}{2}\left(1+\sqrt{1+a}-\sqrt{a}\right) = 344\ 864{,}26\ \text{rub/year};$$

The costs for X5 retail group = 652 034,76. rub/year, comparing to the 841 564,47. rub/year in a case of playing alone. For Auchan the costs inquired changed from 534 393,97 rub/year to 344 864,26 rub/year. These results show that the coalition itself and the usage of the ICAC method is profitable and formulates the savings for each player. In order to obtain the cost savings, the difference between costs inquired in alone game and costs inquired in a coalition is calculated. In this example, cost savings for Auchan equal 189 529,70 rubles per year, for X5 retail group = 189 529,7 rubles per year.

In our example with X5 retail and Auchan supermarkets, the demand rate for companies is different and thus the order size for both of them equals

$$q = \sqrt{1+a}\sqrt{\frac{2k\lambda}{h}} = \sqrt{1+2{,}48}\sqrt{\frac{2*20\,769{,}23*5\,000\,000}{4000/3200}} = 797\,519{,}23 \text{ packages}$$

$$\text{Total q without collaboration} = 2*\sqrt{\frac{2k\lambda}{h}} = 2*427\,515{,}18 = 855\,030{,}36 \text{ packages.}$$

The order size changed from 855 030,36 packages per order to 797 519,23 packages. These numbers will decrease the inventory level, reducing holding costs and enabling more efficient way of cost distribution.

Following the method, as the order size changed and became smaller, the EOQ graph should be changed in order to reflect the Inventory/Time ratio.

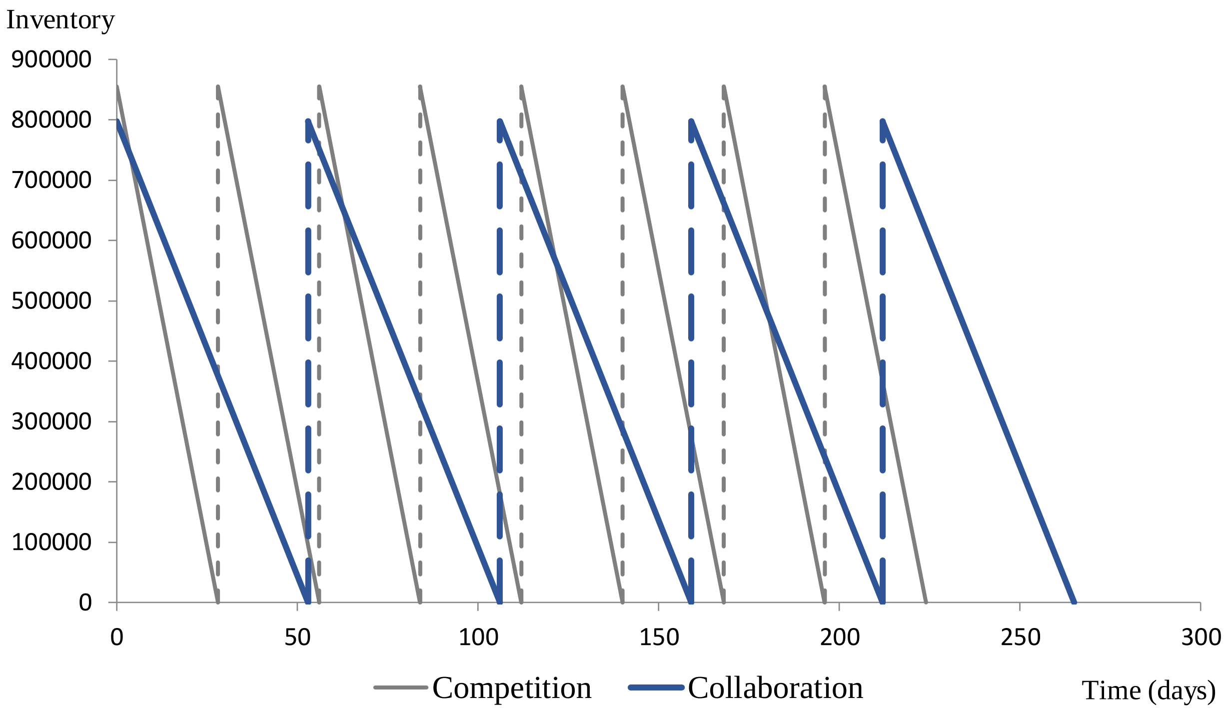


Figure 3.2 ICAC method of collaboration

The order frequency increased, now the orders are placed more often, but the inventory level is much smaller because the order size also decreased. These changes are helpful for better realization and understanding of the demand fluctuations and customer needs. It enables companies to be more flexible and agile, that are the Core drivers of success.

3.3 Results and outcomes

The need to be efficient for the companies and a constant optimization of working processes by managers are core drivers of the success of a company. The supply chain is one of the essential parts of a business processes that can be changed, restructured and optimized to bring benefits. In order to change the company performance, the logistics processes on the whole supply chain can be adjusted. One of the way to optimize efficiency is to collaborate. Small companies are eager to create partnerships (Yilmaz and Savasaneril 2012).

One of the most significant item of expenditures in the supply chain department is inventory. Most companies have to deal with huge inventory level to stay competitive and win the market position, while the stock expenses are enormous. For some companies, pre-orders for demand predictability or stable price and quality competition to minimize the bullwhip effect can be applied. However, demand for different products of the retail chains may vary dramatically. Even if the demand for some daily products more or less stable and predictable, as well as for the grocery, some external factors may change the demand in different ways in a day. For instance, the positive advertisement by celebrity may contribute to the shortage in a store, while the powerful people can reduce the demand and create the surplus. Moreover, the market share determines the demand rate of a supermarket. The more supermarkets retail chain has, the higher the demand rate is. Another source of demand fluctuation is price differentiation of products and diversification through enlarging price categories available within one retail chan.

The approach proposed in a paper helps to eliminate the storage and inventory management problems that occur very often on practice. In order to make warehousing more efficient, companies can cooperate. This reduces costs, increase customer satisfaction rate and makes the operations more efficient. In the ICAC method, however, the cooperation assumes not only the collaboration with different players who companies do not compete with on any level, but also the collaboration with competitors. In such a game, the cost savings are achieved, that prove the need to collaborate.

Moreover, when companies play jointly, the questions of sharing the benefits and cost allocation occur constantly. In the ICAC method, the stable cost allocation rule is proposed. In assumes the symmetric cost distribution and thus promotes the wish to collaborate and keep the players in a game. The extended method assumes different demand rates and allocate costs respectively.

In this master thesis, costs for individual storing of 1 product category on 1 sq.m. of warehouse per year of two players are analyzed. The method is applied to the retail chain (Auchan and X5 retail group). For companies, seeking the optimization, it is practically useful. The results are found. The costs Auchan should inquire in a case it plays alone = 534 393,97 rubles/year, for X5 retail group = 841 564,57 rub/year. If companies cooperate, the total costs may be lowered to 996 899,03 rubles (instead of 1,37 mln. - the sum of costs in alone games). These results demonstrate the logical reason for companies to collaborate.

However, in real life the question of how to allocate costs in a coalition arises much more often that the question of the need to cooperate. In order to share the costs, new stable rule may be proposed. It shares the costs in such a way that players are willing to stay in a coalition, the decision is stable and nobody wants to deviate from this sharing allocation. To each cooperative game, it assigns a unique distribution among the players of a total surplus generated by the coalition of all players. For the extended method with different demand rates, the Shapley Value is used. In a coalition, the costs for Auchan = 344 864,26 rub/year, for X5 retail group = 652 034,76 rub/year. This result should satisfy both players and keep them in a coalition.

The ICAC method proposed in this master thesis has many advantages comparing to the existing approaches. Firstly, the method suggests the collaboration of competitors that is not a widely-used practice nowadays. In many cases, companies tend to collaborate only if they are engaged in the mutual activities and do not compete on the level they can collaborate. However, this omission is needed if companies are seeking for optimization. Secondly, there is a sense to collaborate with proposed method as the costs are decreasing and the synergy effect takes place. Finally, the method proposes a stable allocation rule that creates a distribution that satisfy all the members of the coalition. Cost allocation problem is also solved. The initial method is symmetric that means that costs inquired by each party are equal and the cost allocation is stable. But at the same time, the symmetry of the method is its limitations that can be considered and investigated in future. That is why, the extended method is proposed. The difference in demand rate causes different cost allocation (not symmetric). However, in this master thesis, the extended method assumes only two players. Increased number of players in a coalition may be seen as a limitation of this work and possible future research.

Conclusions of chapter 3

In this chapter, the ICAC method is applied on example of retail companies. The examples are chosen according to several criteria: competing companies that rent the same warehouse, sell homogeneous products that are available in both retail channels. The data was found in consulting reports by Colliers International and Knight Frank.

In our example, X5 retail group and Auchan supermarkets suit all the preconditions because they are 2 out of 10 leading companies in retail industry, they are competitors that lease the same warehouse in Pushkinsky District of Leningrad region, their product diversity is very close to each other and includes the same category of homogeneous products. Because the demand rate of these companies differs, the asymmetric case method was used.

The method applied showed significant change in costs inquired by every retail chain in both scenarios – a game without collaboration and in a game with collaboration. The results showed that the collaboration by competitors has a positive influence on cost savings in inventories and thus stimulates the collaboration. In our example, the surplus generated by companies equals

379 959,41 rubles and these numbers were only counted for the storing of sugar in 1 kg. packages. That means, that reals savings after ICAC method implementation are much higher. In addition, the method changed the order size that can affect the fixed and holding costs, reducing them in future.

Moreover, the ICAC method proposes a stable cost allocation decision based on game-theoretic approach. The result is a Shapley Value that is inside the Core, meaning that the compromise for both players are found and no one wants to deviate from the coalition: it is economically unbeneficial.

Yet the savings calculated may be not so essential for big market players, for small enterprises, savings might be crucial. The ratio of inventory costs in total costs structure of a company is higher for the small companies than for the giants of retail industry. That is why, the benefits of ICAC method implementation for small companies (that spend more on the inventory storage and warehouses rent) are obvious and are economically profitable.

Chapter 4. Conclusions and implementations

4.1 Theoretical contribution

Analysis of existing scientific literature showed, that there is always a room for optimizing business processes and making the operations more efficient. Companies are always willing to decrease costs and starve to better performance. One of the possible solutions is horizontal collaboration among companies. Horizontal cooperation corresponds to identifying and exploiting win–win situations among companies at the same level of the supply chain in order to improve performance (Cruijssen, Dullaert and Fleuren 2007). The main purpose of this master thesis is to create new method that helps retail companies to save costs in cooperation by aggregating inventories and applying game-theoretic approach to allocate costs. It also helps to meet the demand better and achieve the higher customer satisfaction rate.

Investigating the studies on the cost allocation in collaborative logistics topic, the gap in cost allocation algorithm for companies was identified. In order to fill it up, the main research question "How can companies allocate costs from sharing warehouse capacities?" was answered. The main input of this study to the science as well as to the practice is the ICAC method for cost allocation and cost savings suitable for any company.

In practice, there is a lack of collaboration practices among companies due to the intimacy and privacy that omits many potential benefits. Scientific literature on these topics covers a lot of possible advantages of collaboration, validate the impact of different forms of it on the performance. However, methods that assume collaboration with competitors are absent. In addition, there are not so many methods that can explain the cost and surplus distribution algorithm, satisfy all the members and keep them in a coalition.

In this master thesis, the ICAC method for cost allocation in cooperative game on the example of aggregative warehouse capacities of competing companies is proposed. It is based on the famous and widely used Economic Order Quantity Model, but contains improvements. Applying this framework helps companies to save costs and then allocate them. In such a distribution, every player is willing to collaborate and agrees on the allocation decision because it is unique and located inside the Core. Moreover, the method builds better demand predictability because by applying ICAC method, companies do not keep huge inventories and can change the stocks very fast when needed. The ICAC method also promotes the flexibility of companies in a sense that they can react on the stock level changes in supermarkets much faster or they can put another type of inventory on the free shelves.

Summing up, the ICAC method of cost allocation in inventory management for retail companies is proposed and contributes to the improvements of the existing solutions that are lack of practical orientation or contain many restrictions that makes them less applicable. For example, some studies assume no more than eight coalition players. However, the synergy of the collaboration, measured in relative terms, increases with the size of the coalition. (Lozano et al. 2013). This possess that adding new member in a coalition can open new opportunities and bring additional benefits. Proposed in this master thesis method helps to eliminate this restriction. ICAC method proves that with the increase number of players, the order size decreases, inventory level goes down and the savings tends upstream.

The main contribution of the ICAC method is that it helps the company to collaborate on horizontal level, decrease the inventory level and it proposes a stable cost allocation decision. The fact that the decision is Shapley Value and is located inside the Core proves that it is stable and increase the initiative of companies to collaborate.

4.2 Managerial implication

The ICAC method is practically oriented and can be implemented by any companies that lend warehouses. Results of this master thesis are obtained from the retail chains. The ICAC method shows that in order to get positive result and perform better, the collaboration with competitors is an option. For managers, this concept can be radically new, however, being aware of the possible benefits results in more efficient management system.

For companies, to start collaboration several steps are needed to be taken. Firstly, company's managers have to realize that they are renting warehouse and want to improve inventory management within the organization. Once managers know that their competitors with similar product categories renting warehouse too, they can proceed with collaboration practices. To begin it, representatives from all the companies that are willing to collaborate have to agree on several aspects: from the moment they start collaboration, they storing inventory together. Moreover, the demand is aggregated and based on ICAC method, managers decide what amount to order, when the order has to be placed and how to inquire costs. In addition, with collaboration, fewer people can manage it and handle the orders placing and storing control.

To observe the changes in variables, sensitivity analysis is conducted. It helps to discover the relationship between dependent and independent variables as well as the impact of dependent parameters under given restrictions and assumptions. In this example, the impact of variables ($k, \lambda,$ and h) on the order size and order frequency is examined.

Firstly, the order size and order frequency is examined for each company from our examples playing alone. According to the calculations in previous chapter, the parameter values are:

$k = 20\ 769{,}23;$

$\lambda = 5\ 500\ 000;$

$h = 1{,}25;$

The estimated order size and order frequency are shown on the Figure 4.2.1

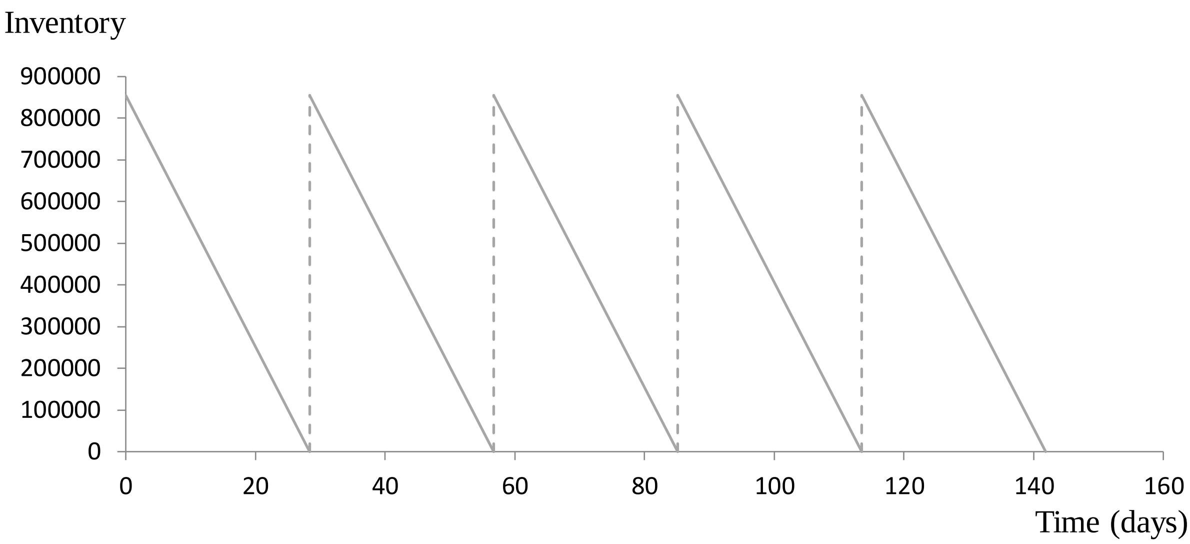


Figure 4.2.1 No collaboration game order size

It can be noticed from the figure, that the order size is the same each time the order is places and the order frequency is 28 days. However, if we apply ICAC method, the changes appear immediately. They can be found on the Figure 4.2.2.

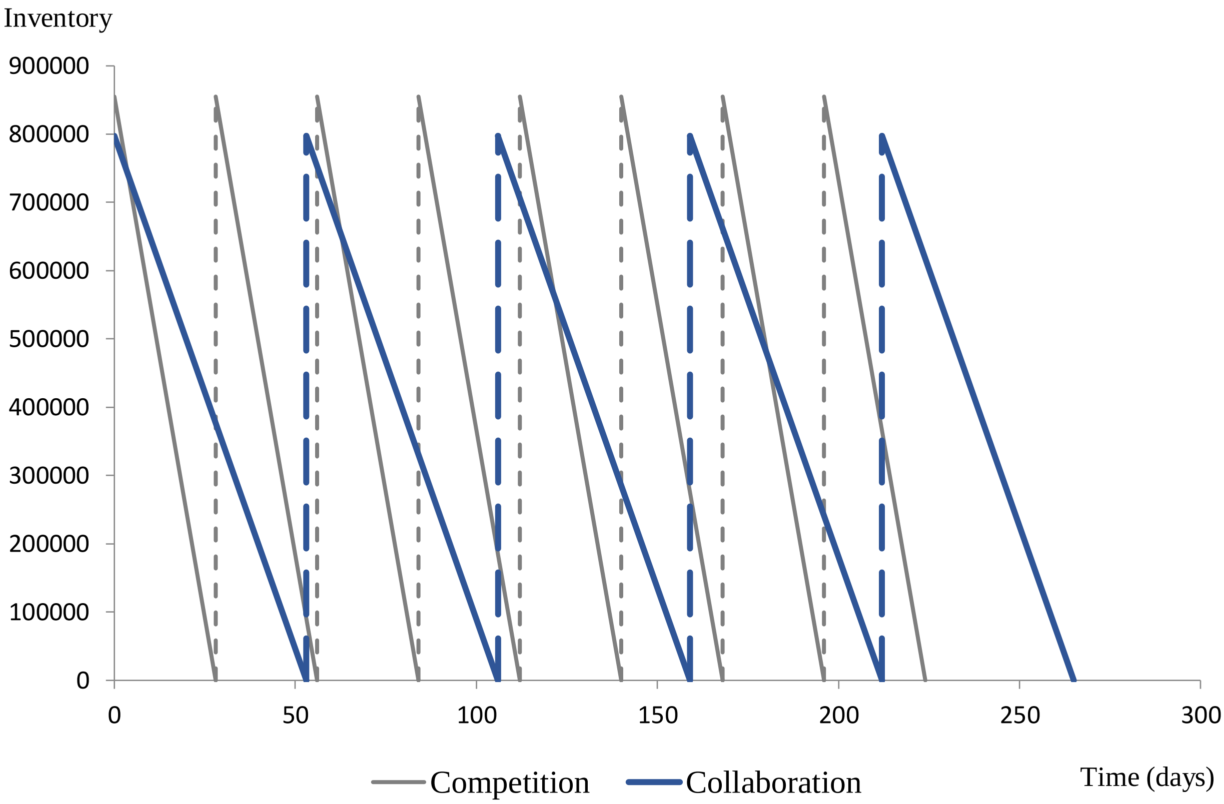


Figure 4.2.2 ICAC method order size changes

Comparing figures 4.2.1 and 4.2.2, the difference in order size may be seen. The blue line stands for cooperative orders and grey is for the competitive game without cooperation. The orders became smaller and thus, the inventory level decreases (assuming the demand rate is stable).

Moreover, the order frequency changes can be also analysed. In order to examine it, a new parameter if estimated. The changes of the order size are discovered. Comparing to the no collaboration game, it changes from 28 days to 53 days, meaning that the orders now in a cooperation with ICAC method are less often and are placed each 53 day.

This approach can be used in real life in order to see the impact of the ICAC method and understand the outcomes of the possibly implemented strategy. These practical insights are very indicative and are easy to understand.

4.3 Limitations and recommendations for future research

Despite the advantages of ICAC method, there are some limitations that should be pointed out. To begin with, even the examined research articles state there is a gap and the EBSCO search result supports it, the fact that such a method can be developed and just be accepted in print in scientific literature cannot be omitted. Secondly, the demand uncertainty and its fluctuations due to different external factors can be another limitation. The willingness to cooperate is another obstacle. In some countries, for example in Russia, the incentive to share information regarding sales volume, price formation can be very low. Sometimes the information perceived as too private to be shared with other companies, especially with the competitors, even if this method helps to stimulate the costs saving.

Moreover, the relevance of the warehouse renting varies from region to region in Russia. Some companies prefer to build its own distribution center in the biggest cities or in the middle of the country to have a full control over it. In addition, the asking rental price differs very much across the country. According to the market position and rental rate, companies tend to choose where to rent the facilities. This can result in a remoteness of competitors and eliminate the collaboration practices.

Furthermore, the proposed method for collaboration and cost allocation for any number of players is symmetric. It means that the payoff is distributed among players equally. It assumes the equal distribution, that is stable and satisfy all the members of a coalition and keep them in a game. However, if the value each player brings to the coalition is different, the equal distribution can be seen as a limitation. As for the asymmetric case, due to the time constraints, it is adopted only for 2 players. But it can be changed to fit any number of players in future.

Finally, in real life, the proposed framework is needed to be adopted to decrease its level of ideality and theoretically. It should be stated, that another method that helps to explain and validate other variables should be also developed and described. The method should assume different fixed or variable costs for the companies as well as the increased number of players. This will make it more practical and applicable.

Conclusions of chapter 4

In this master thesis, the ICAC method is described. It helps to allocate costs from horizontal collaboration on inventory level of competing companies using game-theoretic approach and generate surplus. The method fills the gap in a scientific literature on the cost allocation mechanism because the decision is stable as it is the Shapley value inside the Core of the game. It allows a lot of participants in a coalition without any restriction and it creates a motivation for companies to collaborate.

The sensitivity analysis is helpful to see the changes in order size and order frequency. Applying ICAC method, companies will decrease the order size as well as the inventory for this particular product category and place orders less often. It means, that the number of people responsible for the planning and placing orders maybe changed downwards. This as well as the method itself generates the surplus by reducing costs for inventory management.

However, despite the possible benefits, the method has several limitations that can be assumed for future investigations. Firstly, the leadtime assumes to be independent from the order size. Next, the replenishment occurs at the exact timeframe we need it, meaning that the stockouts or surpluses in inventory are forbidden. Finally, the asymmetric method proposed is adopted only for two players. All these factors as well as the willingness to collaborate can be seen as the next improvements of the ICAC method proposed.

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Appendices

Appendix 1. ICAC method

$$\alpha_1 \leq \gamma$$

$$\alpha_i + \alpha_j \leq \sqrt{2}\,\gamma$$

$$\sum_{i=1}^{n} \alpha_1 \leq \sqrt{n-1}\gamma$$

$$\sum_{i=1}^{n} \alpha_1 \leq \sqrt{n}\,\gamma$$

$$\alpha_i = \frac{\sqrt{n}}{n}\gamma$$

$$n \geq 2$$

$$\frac{2\sqrt{n}}{n}\gamma \leq \sqrt{2}\gamma$$

$$\frac{2\sqrt{n}}{n} \leq \sqrt{2}$$

$$\frac{2}{\sqrt{n}} \leq \sqrt{2}$$

Shapley Value

$$\vartheta_i = \sum_{S, i \epsilon S} \frac{(S-1)!\,(n-S)!}{n!}\;[V(S) - V(S\backslash i)]$$

$$V(S) = \sqrt{s}\gamma \qquad\qquad V(S\backslash i) = \sqrt{S-1}\gamma$$

For 2 players:

$$\vartheta_i = \frac{1}{2}\gamma + \frac{1}{2}\left[\sqrt{2}\gamma - \gamma\right] = \frac{1}{2}\gamma + \frac{\sqrt{2}}{2}\gamma - \frac{1}{2}\gamma = \frac{\sqrt{2}}{2}\gamma$$

For 3 players:

$$\vartheta_i = \frac{1}{3}\gamma + \frac{1}{6}2\left(\sqrt{2}\gamma - \gamma\right) + \frac{1}{3}\left(\sqrt{3}\gamma - \sqrt{2}\gamma\right) = \frac{1}{3}\gamma + \frac{1}{3}\sqrt{2}\gamma - \frac{1}{3}\gamma + \frac{\sqrt{3}}{3}\gamma - \frac{\sqrt{2}}{3}\gamma = \frac{\sqrt{3}}{3}\gamma$$

$$[V(S) - V(S\backslash i)] = [\sqrt{s}\gamma - \sqrt{s-1}\gamma]$$

$$\vartheta_i = \sum_{S=1} \frac{(S-1)!\,(n-S)!}{n!}\,\frac{(n-1)!}{(s-1)!\,(n-1-S+1)} =$$

$$= \sum_{S=1} \frac{(S-1)!\,(n-S)!}{n!}\,\frac{(n-1)!}{(s-1)!\,(n-S)}\,\left[\sqrt{s}\gamma - \sqrt{s-1}\gamma\right] = \sum_{S=1}^{n}\frac{1}{n}[\sqrt{s}\gamma - \sqrt{s-1}\gamma] =$$

$$= \tfrac{1}{n}\gamma \textstyle\sum_{S=1}^{n}[\sqrt{s} - \sqrt{s-1}] = \tfrac{1}{n}\gamma\left(-\sqrt{0} + \sqrt{n}\right) = \tfrac{\sqrt{n}}{n}\gamma$$

Appendix 2. Subadditivity principle fulfillment

In order to investigate the subadditivity principle, the statement that the total costs inquired by partners without collaboration are higher than the costs inquired in a collaboration.

The costs for players in a case of asymmetry demand rate are:

$$C_1 = \sqrt{2k\lambda h} = \sqrt{a}\sqrt{2k\lambda h},$$

$$C_2 = \sqrt{2k\lambda h}$$

where a - coefficient that equalizes the demand rated for both players

$$C_1 + C_2 = (1+\sqrt{a})\sqrt{2k\lambda h}$$

$$C_{1,2} = \sqrt{2k(1+a)\lambda h} = \sqrt{1+a}\sqrt{2k\lambda h}$$

Let assume $\sqrt{2k\lambda h} = \gamma$

Now it should be checked that the total costs of coalition are less then total costs of no-cooperative game:

$$\left(1+\sqrt{a}\right)\sqrt{2k\lambda h} > \sqrt{1+a}\sqrt{2k\lambda h}$$

Dividing both parts by $\sqrt{2k\lambda h}$, the equation equals

$$1+\sqrt{\mathrm{a}} > \sqrt{1+\mathrm{a}}$$

$$1 > \sqrt{1+\mathrm{a}} - \sqrt{\mathrm{a}}$$

$$1 > \frac{(\sqrt{1+\mathrm{a}}-\sqrt{\mathrm{a}})(\sqrt{1+\mathrm{a}}+\sqrt{\mathrm{a}})}{(\sqrt{1+\mathrm{a}}+\sqrt{\mathrm{a})}}$$

$$1 > \frac{1+a-a}{\sqrt{1+\mathrm{a}}+\sqrt{\mathrm{a}}}$$

$$1 > \frac{1}{\sqrt{1+\mathrm{a}}+\sqrt{\mathrm{a}}}$$

$$\mathrm{a} > 0,$$

because it is a market share taken by a company.

It means that we divide 1 by any value that is higher than 1. Thus, the equality is satisfied.

Finally, it follows that the principle of subadditivity is fulfilled: total costs in a coalition are less than total costs in a case companies do not cooperate.

Appendix 3. Shapley Value inside the Core verification

Let assume $\sqrt{2k\lambda h} = \gamma$

$$\vartheta_1 = \frac{1}{2}\sqrt{a}\gamma + \frac{1}{2}\left(\sqrt{1+a}\gamma - \gamma\right) = \frac{1}{2}\left(\sqrt{a}\gamma + \sqrt{1+a}\,\gamma - \sqrt{a}\,\gamma\right) =$$

$$= \frac{\gamma}{2}\left(\sqrt{a} + \sqrt{1+a} - \sqrt{a}\right) = \frac{\gamma}{2}(\sqrt{a} + \sqrt{1+a} - 1)$$

$$\vartheta_2 = \frac{1}{2}\gamma + \frac{1}{2}\left(\sqrt{1+a}\gamma - \sqrt{a}\,\gamma\right) = \frac{\gamma}{2}(1 + \sqrt{1+a} - \sqrt{a})$$

We need to compare the costs inquired by a player in a coalition to the costs comparing if he plays alone.

If he plays alone, the costs inquired equals $\sqrt{a}\,\gamma$,

in a coalition, the costs inquired equals $\frac{\gamma}{2}(\sqrt{a} + \sqrt{1+a} - 1)$

$$\sqrt{a}\,\gamma > \frac{\gamma}{2}(\sqrt{a} + \sqrt{1+a} - 1)$$

Because γ has a positive value,

$$\sqrt{a} > \frac{\sqrt{a} + \sqrt{1+a} - 1}{2}$$

$$\sqrt{a} = \frac{\sqrt{a}}{2} + \frac{\sqrt{1+a} - 1}{2}$$

$$\frac{\sqrt{1+a} - 1}{2} < \frac{\sqrt{a}}{2}$$

$$\sqrt{1+a} - 1 - 2\sqrt{a} < 0$$

$$\sqrt{1+a} - 2\sqrt{a} < 1$$

$$\sqrt{1+a} < 1 + \sqrt{a}$$

$$\frac{(\sqrt{1+a} - \sqrt{a})(\sqrt{1+a} + \sqrt{a})}{(\sqrt{1+a} + \sqrt{a})} < 1$$

$$\frac{1 + a - a}{\sqrt{1+a} + \sqrt{a}} < 1$$

$$\frac{1}{\sqrt{1+a} + a} < 1$$

For the second player,

$$\gamma > \frac{\gamma}{2}(1 + \sqrt{1+a} - \sqrt{a})$$

$$1 > \frac{1 + \sqrt{1+a} - \sqrt{a}}{2}$$

$$2 > 1 + \sqrt{1+a} - \sqrt{a}$$

$$1 > \sqrt{1+a} - \sqrt{a}$$

$$1 + \sqrt{a} > \sqrt{1+a}$$

$$1 > \sqrt{1+\mathrm{a}} - \sqrt{\mathrm{a}}$$

$$1 > \frac{(\sqrt{1+\mathrm{a}} - \sqrt{\mathrm{a}})(\sqrt{1+\mathrm{a}} + \sqrt{\mathrm{a}})}{(\sqrt{1+\mathrm{a}} + \sqrt{\mathrm{a})}}$$

$$1 > \frac{1 + a - a}{\sqrt{1+\mathrm{a}} + \sqrt{\mathrm{a}}}$$

$$1 > \frac{1}{\sqrt{1+\mathrm{a}} + \sqrt{\mathrm{a}}}$$

$$\mathrm{a} > 0,$$

This means that the cost allocation in a coalition is less than the cost allocation in a game without cooperation. Moreover, for each player there is no motive to deviate from the allocation mechanism – Shapley Value.